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DESIGN, FABRICATION, TESTING AND DELIVERY OF A SOLAR COLLECTOR

William H. Sims, et al

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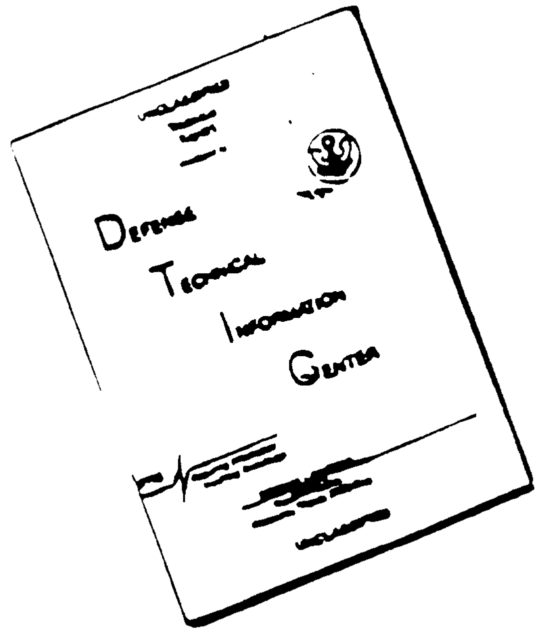

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Final Report

January 1976

Prepared by:

William H. Sims

Robert W. Ballheim

Stephen M. Bartley

Gregory W. Smith

Prepared for:

National Aeronautics and Space Administration/George C. Marshall Space Flight Center

Marshall Space Flight Center, Alabama 35812

Contract No. NAS8-31326

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Chamberlain Manufacturing Corporation
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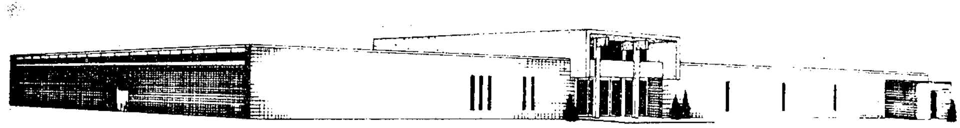

CHAMBERLAIN MANUFACTURING CORPORATION
RESEARCH AND DEVELOPMENT DIVISION

Document No. C8092-PR-012

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Contract No. NAS8-31326

FOREWORD

This report represents the results of work performed by the Chamberlain Manufacturing Corporation, Research and Development Division, for the NASA-Marshall Space Flight Center, Alabama, under Exhibit A of Contract NAS8-31326.

The NASA Contracting Officer's Representative for this study was Mr. Earl Herndon, Organization EP12.

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SUMMARY

Effective 10 January 1975, Chamberlain Manufacturing Corporation was contracted by the NASA-Marshall Space Flight Center under Contract NAS8-31326 to perform a two-phase program encompassing the redesign and fabrication of a solar collector which is low in cost and aesthetically appealing.

In Phase I the Company reviewed the current collector design and then developed a low-cost design based on specific design/performance/cost requirements. Throughout this phase selected collector component materials were evaluated by testing and considerations of cost, installation, maintainability and durability. The resultant collector design was composed of six major components: absorber plate, insulation, frame, cover, desiccant and sealant. Each component was chosen and/or designed to meet the primary objectives of the program - establishing a collector design and manufacturing techniques which yield low cost and aesthetically appealing collectors suitable for mass production. The components are described in detail within this report.

Upon approval of the collector design by the Contracting Officer's Representative, Phase II of the program began. Three collector prototypes were fabricated by the Chamberlain Monroe (Georgia) Division and shipped to the Research and Development Division where the absorber plates and covers were assembled to the frames. The three prototypes were evaluated for both nonthermal and thermal characteristics. Tests included static load tests of covers, burst pressure tests of absorber plates, and tests for optical characteristics of selective absorber plate coatings. Thermal performance testing was conducted using instantaneous efficiency methods.

The three prototype collectors (two with absorber plates coated with black chrome over bright nickel and one with the absorber plate coated with black copper over bright copper) were shipped to Marshall Space Flight Center 18 November 1975 for use in their solar heating and cooling test facility.

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1. INTRODUCTION

The development of a low-cost solar collector may take one of several approaches in order to meet the requirement of being, in fact, low cost. The very definition of low cost in absolute terms would mean that the collector cost to the consumer would be minimum dollars per square foot. In the present day inflationary spiral of energy costs, however, a low cost collector is defined more properly as that unit which will provide the consumer a higher energy gain per dollar spent for the same square footage. This philosophy was the approach taken by Chamberlain in the development of a low-cost solar collector.

Each component which has been selected to go into the makeup of the NASA-MSFC solar collector was chosen because it met criteria established in terms of operating conditions, safety margin, effect on collector efficiency, fabricability, lifetime and cost-effectiveness.

The cost effectiveness of each component has been the overriding parameter in each case where there was a choice based on the other criteria.

One factor which has been evaluated carefully during this program is the building code acceptability of the collector components. Since Corporate resources had been committed to develop a line of commercially available, viable solar collectors, a parallel, Company-funded research program was underway when the NASA-MSFC program was initiated. A major concern, aside from the consumer cost, was code acceptance. The single component which has proven to be of most significance in relation to the many building codes is the insulation used in the collector module for thermal protection.

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1. INTRODUCTION

Many of the solar collectors available to the public today use standard fiberglass insulation. Experience has shown that the thermal protection offered by this insulation is not as good as the rigid foam insulations. Also, if a failure occurs in the absorber plate or if the collector cover(s) fail, the loose fiberglass insulation will absorb a quantity of vapor, resulting in a "packing" of the insulation and large increases in the thermal conductivity. Thus the heat losses from the collector become unacceptable.

The general class of rigid foams is superior to the fiberglass in heat protection, moisture absorption, and longevity, but has a poor record in the areas of fire spread and smoke generation. The manufacturers of the rigid foam are well aware of this fact, and today there are foams available which contain fire retardants. The availability of foams meeting ASTM standards for fire spread and smoke generation is a reality, and more will be made available as time passes. Several were identified during this program.

The transmissivity and strength of the collector module cover materials have been of major concern in the development of flat plate collectors. Historically, because of the research aspects of most collectors, the transmissivity of the cover material has been a major factor in selecting this component. The building codes used for guideline purposes in the Company-funded research do not allow the use of thin films because of the strength characteristics. In addition, Governmental procurements are now being seen which place very stringent load-carrying requirements on the collector cover material. Working directly with glass manufacturers has resulted in candidate glazing material which meets the load-carrying requirements while at the same time providing transmissivity characteristics approaching that of the thin films. In some cases the thin film transmissivity is less than the glazing used in these collectors.

1. INTRODUCTION

The materials used in absorber plates of some collectors have proven through use that corrosion protection is a serious question. Study of the corrosion problem and what steps must be taken for protection purposes has been investigated by many researchers. Because of the presence of dissimilar materials in a complete system, the question of corrosion prevention is not one of collector protection only. Experience gained through the use of corrosion inhibitors combined with freeze protection fluids in the automotive industry was the basis for material selection for the absorber plate.

The collector cover mounting systems found on most collectors today, including the Chamberlain commercial collector, use either a roll-formed steel housing with gaskets and spacers (for multiple covers), or an aluminum extruded frame similar to those found on insulating windows or doors. Some of these designs have proven to be troublesome from glass breakage. The cause is not clear but thermal stresses combined with chipped edges or high mechanical loading during fabrication are thought to be the cause. Again, experience in the automotive and farm equipment field was found to provide an answer to this problem. Glazing channel designs taken from automobiles, trucks and tractors were the basis for the design of the NASA-MSFC collector cover mounts. The design provides the load-carrying requirement of the glass mount, while at the same time providing a long lifetime and being cost effective.

The components mentioned here, as well as others, are essential to any flat plate solar collector. The primary point retained at all times in the design, development, fabrication and evaluation of the flat plate solar collector has been cost effectiveness. Chamberlain will continue to perform collector development studies, but always with the central theme of providing the ultimate consumer a solar collector which is cost effective. The basic definition of a low-cost collector will, then, be the unit which will provide the user with the largest net heat gain per dollar spent. The collector modules provided as part of the contractual requirements of Contract NAS8-31326 are representative products of this cost effectiveness policy.

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2. CHAMBERLAIN MANUFACTURING CORPORATION SOLAR LABORATORY

The Chamberlain Solar Laboratory is located at the Research and Development Division in Waterloo, Iowa. The laboratory was established following a Corporate decision that solar collector manufacturing was a natural extension of the existing capabilities within Chamberlain. The laboratory has been fully operational since April 1975. Initiation of the Chamberlain prototype collector testing began immediately following operational checkout.

The laboratory was designed and implemented in accordance with Reference 2. This National Bureau of Standards document was (and remains) the only known test method recommended by other Governmental agencies for evaluation of collector thermal performance. Since initiation of testing in the Solar Laboratory, Chamberlain was selected by the National Bureau of Standards as a participant in their "round-robin" test series.

The laboratory contains two independently controlled test loops. This arrangement allows simultaneous testing of two collectors for direct comparison under identical test conditions. All testing is accomplished under outdoor conditions.

Each test loop contains the required equipment and instrumentation to maintain constant operating conditions (other than climatic) within the test loop. This includes both preconditioning and reconditioning heat exchangers. The fluid temperature at the inlet of the collector being tested may be controlled within the temperature range of local ambient to 210°F.

A synopsis in outline format is provided on the following pages, including a schematic (Figure 1) of one of the two identical loops, a photograph of the laboratory control consoles (Figure 2) and a photograph of the mounting rack for the collectors being tested (Figure 3). The mounting rack shown in Figure 3 is adjustable for winter or summer operating solar conditions.

SOLAR LABORATORY CAPABILITY

1. Two Identical Flow Circuits

   a. Positive displacement pump driven by variable speed motor, 0-2 gallon/minute range

   b. Three micron particle filters

   c. Positive displacement flow meter

      (1) 1/2% accuracy, 0-2 gallon/minute

      (2) Digital display readout to .001 gallon/minute

      (3) Flow rate recorded on point recorder

   d. Line heaters to obtain and hold desired inlet temperature

      (1) 440 VAC 3,000 Watts

      (2) 110 VAC 0-1,000 Watts Controlled by variac from console

   e. Sight glass to assure that air is not in the system

   f. Fluid temperature probes and readout equipment

      (1) Measure temperatures within ± .5°F, 0-250°F and differential between inlet and outlet temperatures within ± .2°F, 0-50°F

      (2) Digital display to .1°F inlet and outlet and .01 Δt

      (3) Inlet and difference recorded on point recorder.

   g. Pressure taps at inlet and outlet

      (1) Pressure at inlet ± .25 psi

      (2) Pressure differential across collector ± .025 psi

   h. Expansion Tank

      (1) Allows for expansion and contraction of fluid in system

      (2) By closing valve, air bubbles may be removed from the system in approximately 20 minutes.

   i. Fluid temperature conditioning tank

      (1) Used to cool outlet water to provide stable water inlet to collector.

      (2) Water heater may be used to aid in rapid changing of fluid temperature

2. Other Instrumentation

a. Pyranometer

(1) Real time translator output on recorder

(2) Integrating translator output on recorder

(3) When very accurate readout is required (as when testing transmissivity of different glazing materials) pyranometer output can be read directly on digital voltmeter

b. Recorders - two, 24 channels each

(1) One used to record instrument outputs (water temperature, pyranometer, wind probes, flow meters)

(2) One used for thermocouple outputs

c. Wind speed and direction indicator

d. Wind velocity measuring system

(1) Six probes to measure wind velocity at different points outside the collector. Data on recorder and digital readout.

e. Thermocouples

(1) Monitor and record temperatures at selected areas of the collector - 62 channels available

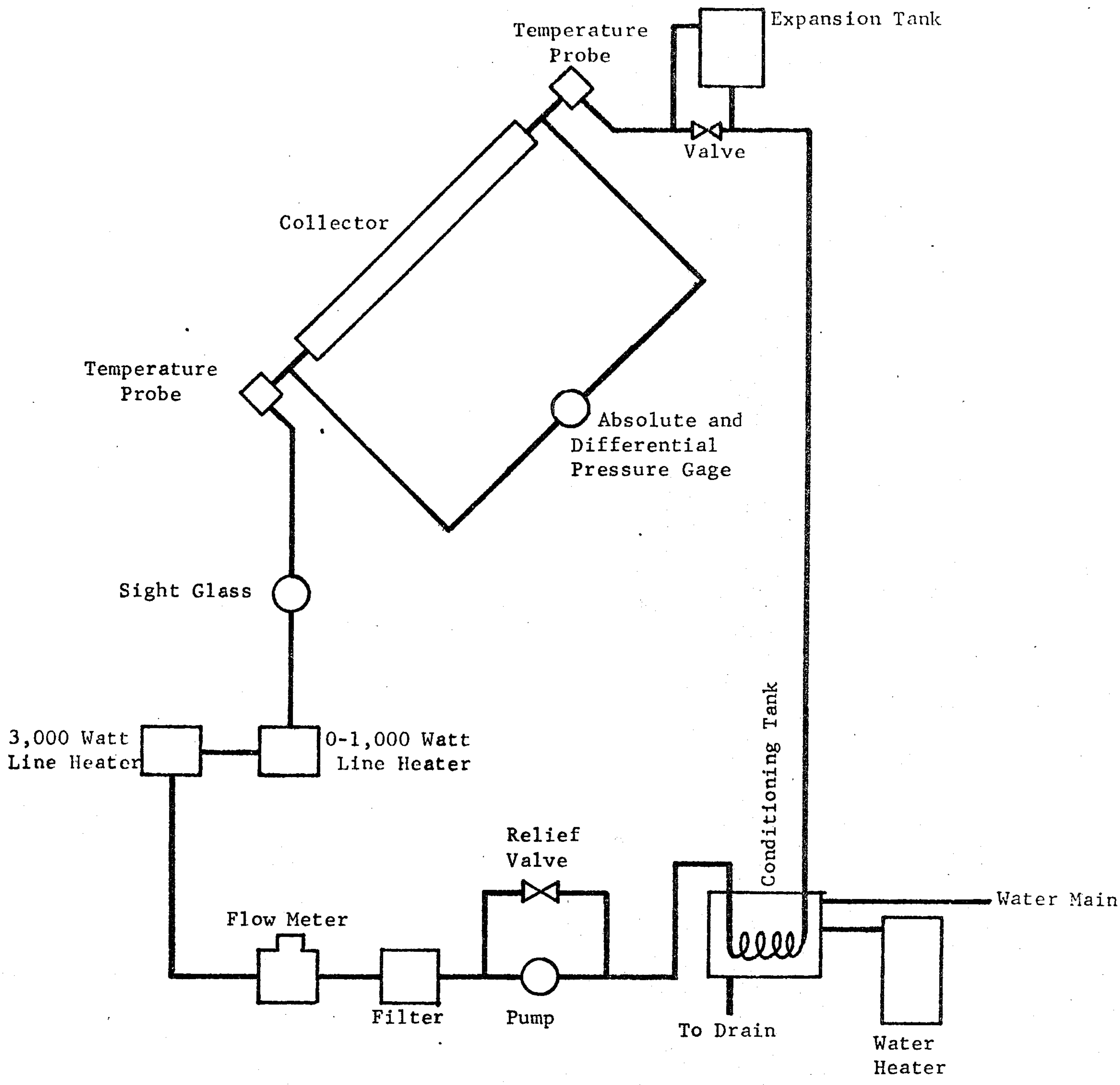

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Figure 1. Solar Laboratory Schematic

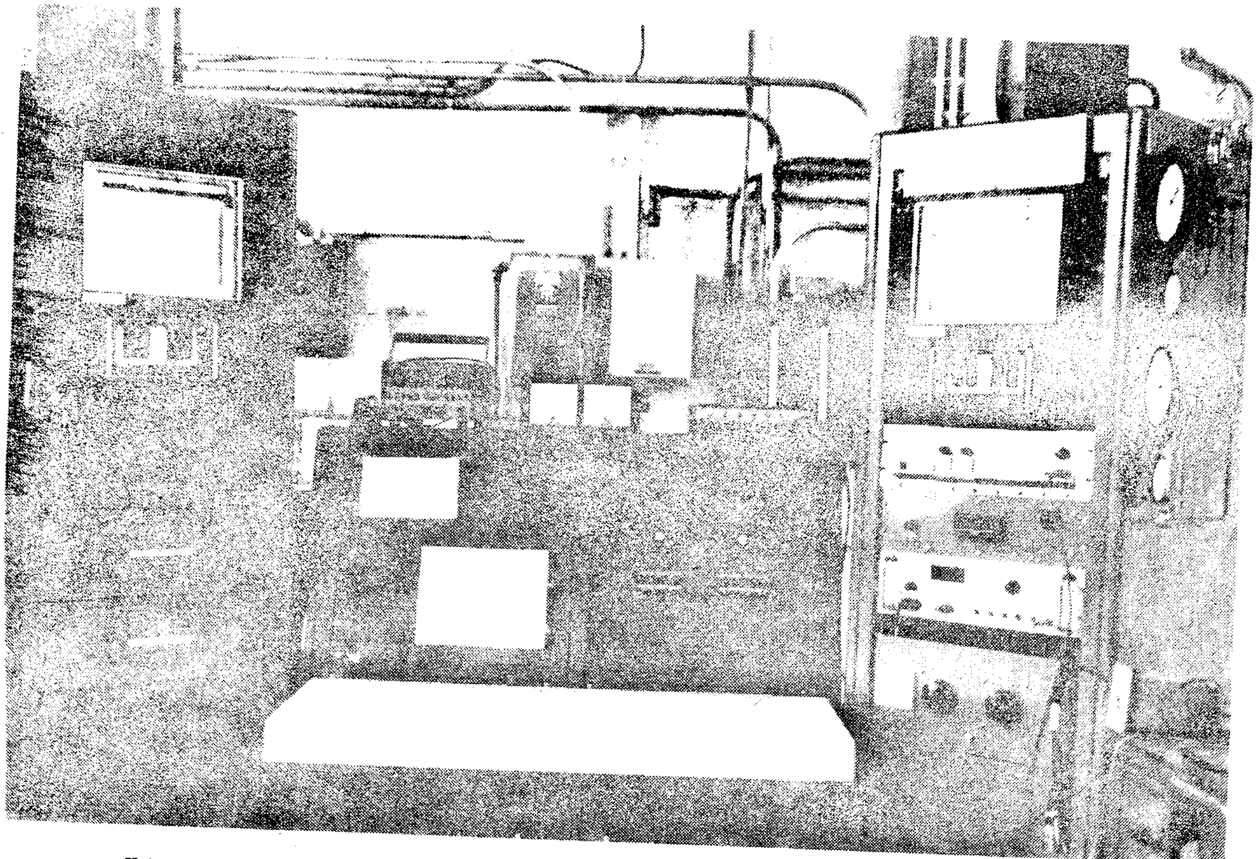

Figure 2. Solar Laboratory Control and Data Collection Center

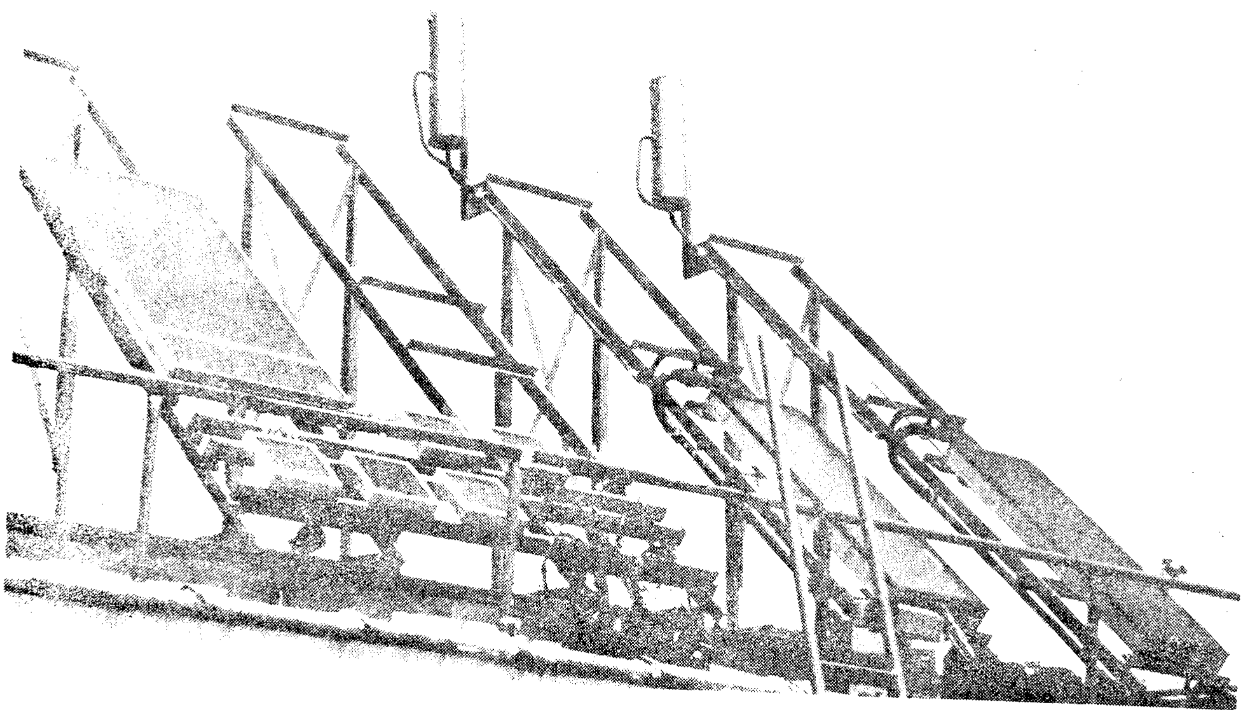

Figure 3. Solar Collector Test Stands

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3. COLLECTOR DESIGN

The design of the NASA-MSFC, flat plate solar collector was selected for high performance while retaining the requirement of being cost effective. Each component selected or designed for forming was evaluated carefully against the alternatives of materials, fabricability and cost. In some cases, such as the frame design, Chamberlain expertise, gained from many years of roll-forming complex cross sections that are used in many industries, was drawn upon.

In this section each component in the collector will be described, with cross-sectional views provided where applicable. In most of the nonmetal components, many candidate materials were evaluated through testing, cost, etc. for possible use. A compilation of the information gained through these studies may be found in the Appendices. An exploded view of the collector is shown in Figure 4 on the following page.

3.1 Frame

The frame, or side rails, of the collector is fabricated from 18-gage, galvanized, cold-rolled steel. The cross section of the frame is shown in Drawing No. J8092-67 on Page 10. The Monroe (Georgia) Division of Chamberlain has the capability to roll-form the cross section as seen in Drawing No. J8092-67. The prototype collector frames fabricated for this program were made using a press brake since procurement of the required rolls to form the cross section would have been cost prohibitive. In quantity productions the roll-forming equipment would be used for fabricating the frame.

The selection of galvanized cold-rolled steel was based almost entirely on economics. The strength required to maintain structural integrity could be provided by aluminum if a thicker cross section were used. Either of

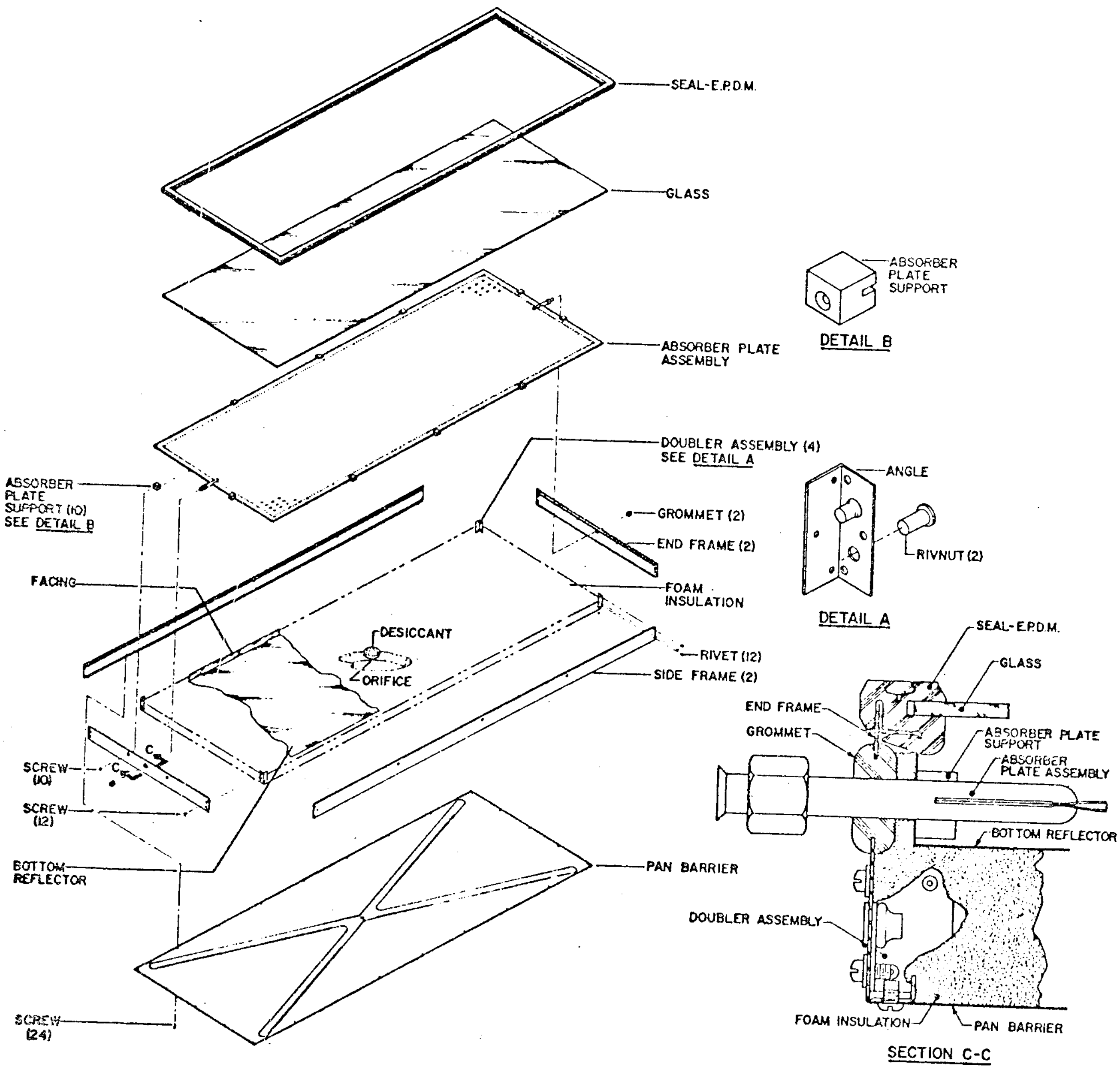
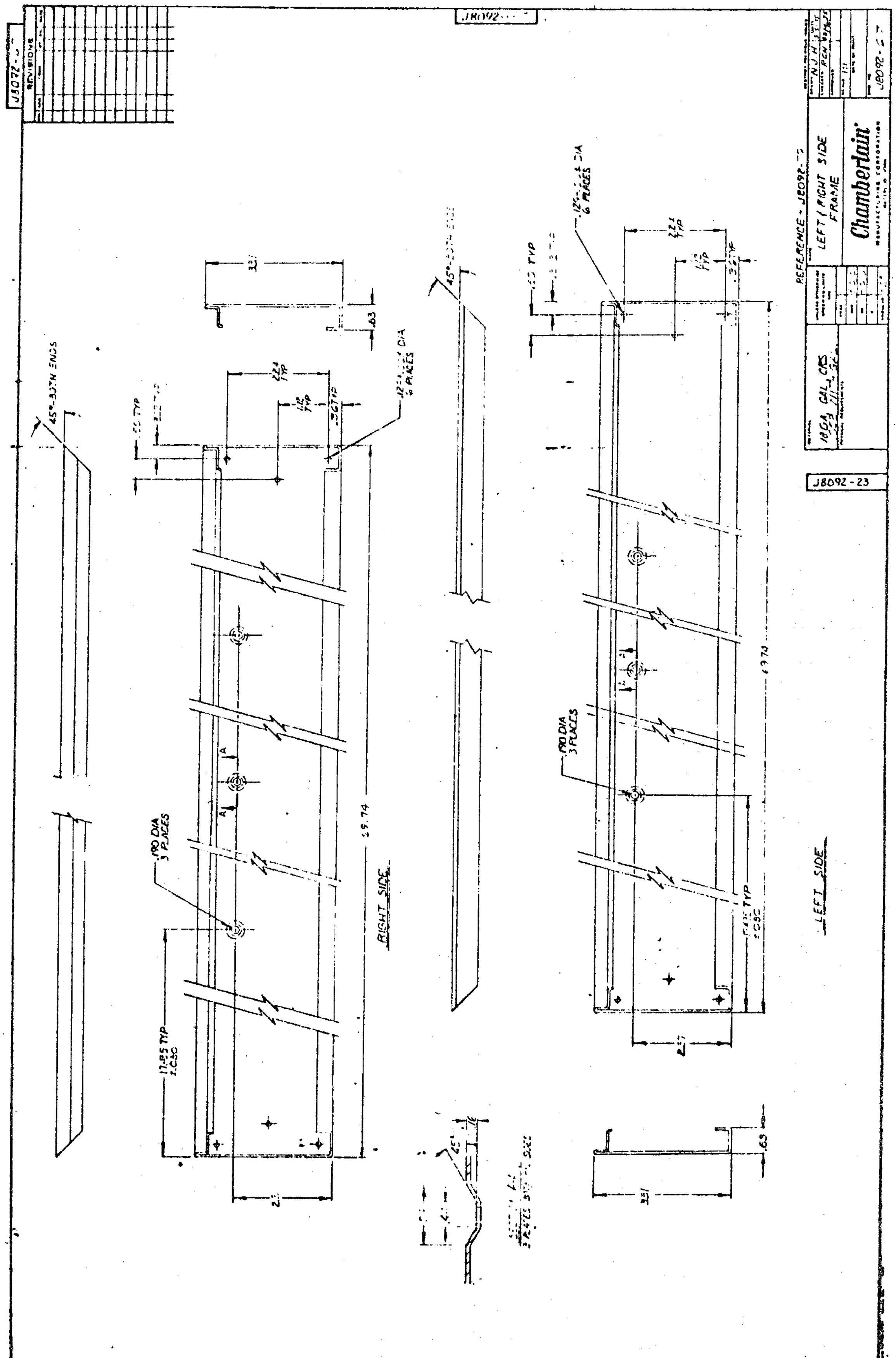


Figure 4. Exploded View of NASA/MSFC Solar Collector



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the materials can be roll-formed with ease. However, the cost of aluminum is approximately three times that of mild steel. Chamberlain's experience has shown that either material when exposed to the elements, results in a longer lifetime when coupled with a protective finish. The galvanized finish on the cold-rolled steel provides the necessary protection at a very small cost. Thus the cold-rolled steel was more cost effective.

The vertical bend on the bottom portion of the frame provides a retaining feature for maintaining the foam insulation position when the foam is poured-in-place or an automated foaming procedure is used. The horizontal portion of the bottom section is used to seal and attach the bottom vapor barrier plate. The horizontal segment on the top of the frame is used for supporting the glass when installed in the EPDM (ethylene, propylene, diene, monomer) glazing channel, while the turn-back shown at the termination of the frame top section provides a locking mechanism to prevent the glazing assembly from being lifted off inadvertently. This feature is needed to prevent the glass from being lifted off the collector module should a strong wind from the back side of the collector occur. A wind expanding across the top of the collector from the back side would cause a pressure drop on the face of the collector, resulting in a pressure differential which could tend to push the glass off the frame.

Mounted on the inside surface of the frame are the doublers and absorber plate supports. These are shown in drawings numbered J8092-26 and J8092-86, respectively, reproduced on the following two pages. The doublers serve two purposes: They serve as mounting surfaces for the two side rails meeting at a 90° angle to form one end and one side, and also they serve as the hold-down points for the mounting feet used to maintain a clearance between the collector bottom and the surface to which the collector is mounted.

J8092-26

REVISIONS

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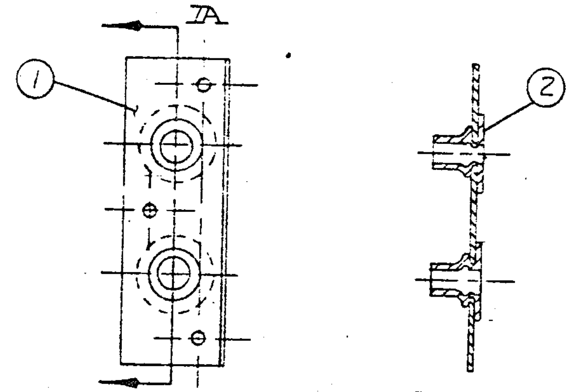

SECTION A A

2	2	J8092-85	$\frac{1}{4}$" RIVNUT
1	1	J8092-27	ANGLE
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MATERIAL

PHYSICAL REQUIREMENTS

UNLESS OTHERWISE SPECIFIED LIMITS ARE

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NAME: DOUBLER ASSY

Chamberlain®
MANUFACTURING CORPORATION
WATERLOO, IOWA

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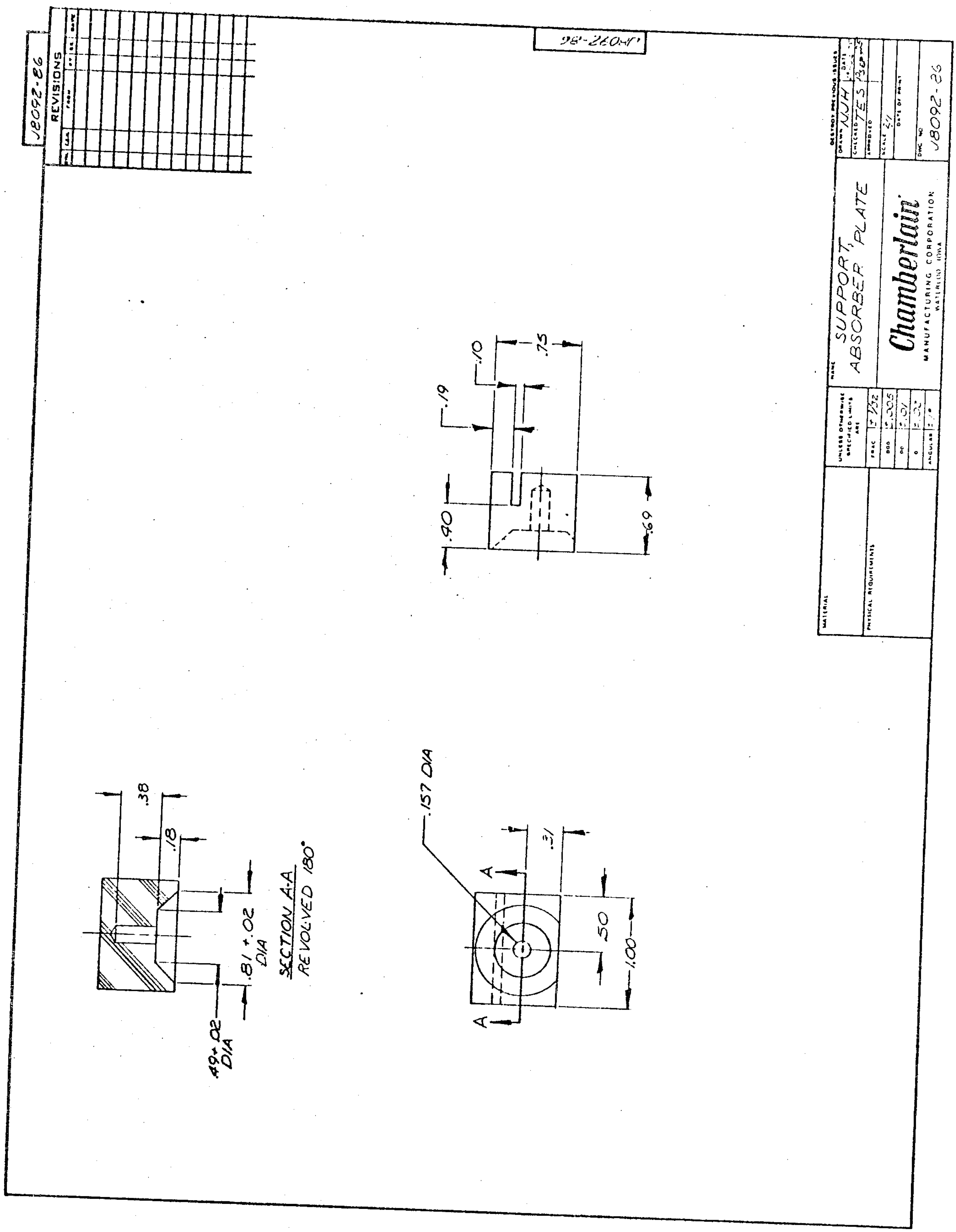

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The doubler assembly is mounted to the short frame lengths (ends) with pop rivets and to the long frame lengths (sides) with sheet metal screws. Sheet metal screws are used to facilitate collector disassembly. The short frame lengths have clearance holes sized for the head of the Rivnut*, which is used to hold the mounting feet in place.

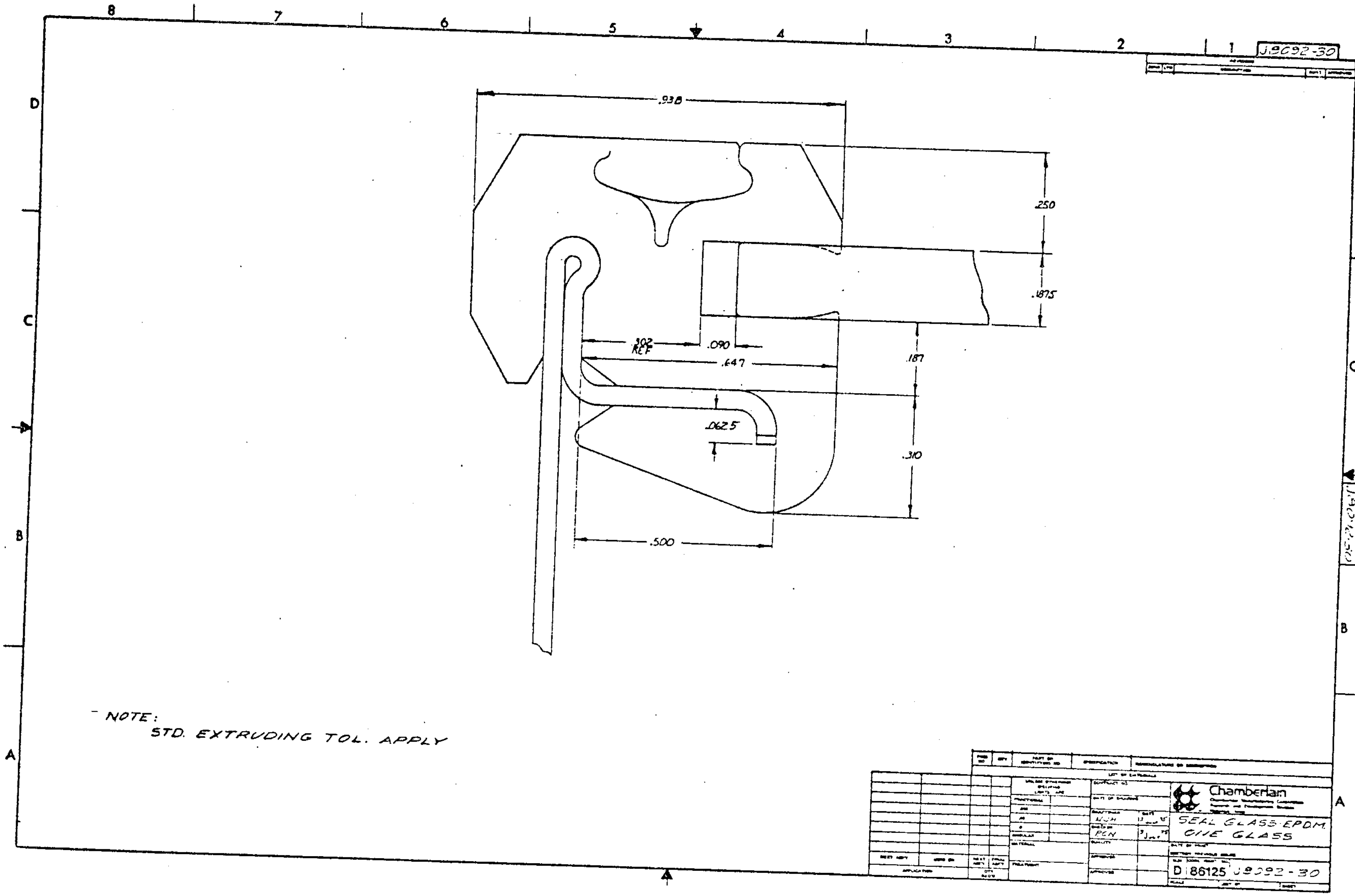
The absorber plate support blocks are made from a phenolic material with very low outgassing characteristics combined with high strength. The collector module uses three support blocks on each side rail and two on each end rail. The design of the support block allows movement of the absorber plate in either longitudinal or lateral direction during thermal expansion and contraction periods, while restraining the plate in the vertical direction. The edge of the absorber plate support block, which mates to the collector frame, has a countersink to aid in location of the block. The frame has a mating countersink which accepts the support block. The support block is then fastened to the frame with a screw.

3.2 Cover

The cover assembly of the solar collector is made up of two pieces: the glazing (glass) and the glazing channel. The glazing used for both the prototype design and the design of a producible 3 foot by 8 foot collector is a 3/16-inch thick, high transmissivity glass produced by the Fourco Glass Company, Clarksburg, West Virginia.

The glazing channel is an extruded cross section made of EPDM (ethylene, propylene, diene monomer) and was fabricated by the Rubber Division of the Ball Corporation, St. Joseph, Michigan. The actual design of the glazing channel was performed by Ball personnel using performance and physical specifications provided by Chamberlain. A cross-sectional view of the glazing channel is shown in Drawing No. J8092-30 on the following page. The design of the glazing channel meets the two critical requirements; providing a water-tight seal and preventing glass movement. The unit is

* A product of B. F. Goodrich.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assembled easily to the frame. Initially the unit is snapped onto the frame, making sure the lower portion of the channel engages the frame in the groove provided for holding the glass down. The glass cover then is rested on the surface of the glazing channel. A tool resembling a tongue depressor, but made from hard plastic, is used to run under the top section of the channel to lift this portion over the edge of the glass. The glass then is positioned evenly around the edges, because a clearance is provided uniformly around the glass to allow for thermal expansion. A light lubricant, which can be provided by the extrusion manufacturer, or water, is then applied to the locking strip. A metal tool resembling an ice pick, but with a very small metal bulb on the end, is then used to engage the locking strip. This procedure, illustrated in Figure 5 on the following page, completes the glass installation, and provides an extremely tight seal. The process is simply reversed for glass removal.

The use of tempered glass enhances the installation in addition to providing the extra strength required. All tempered glass is provided with the edges fired to give smooth edges as opposed to the sharp edges found on annealed glass. The smooth edges provide safer handling characteristics and decrease the chance of chipping the edge during installation.

The minimum cross section provided by the EPDM glazing channel results in an effective aperture larger than is possible with the standard aluminum extrusion used on many collectors. On the prototype collectors provided, which are nominal 2 foot by 6 foot units, the aperture is 91.5 percent of the frame dimensions. On the 3 foot by 8 foot production model the aperture would be an effective 94.3 percent. This parameter is important because of the NASA-recommended method of defining the collector efficiency, and the fact that the aperture is the area through which the collectable energy must pass. The NASA "Interim Performance Criteria for Commercial Solar Heating and Combined Heating/Cooling Systems and Facilities" (Reference 1) defines collector efficiency (instantaneous) as: "The amount of energy removed by the transfer fluid per unit of aperture (entrance window

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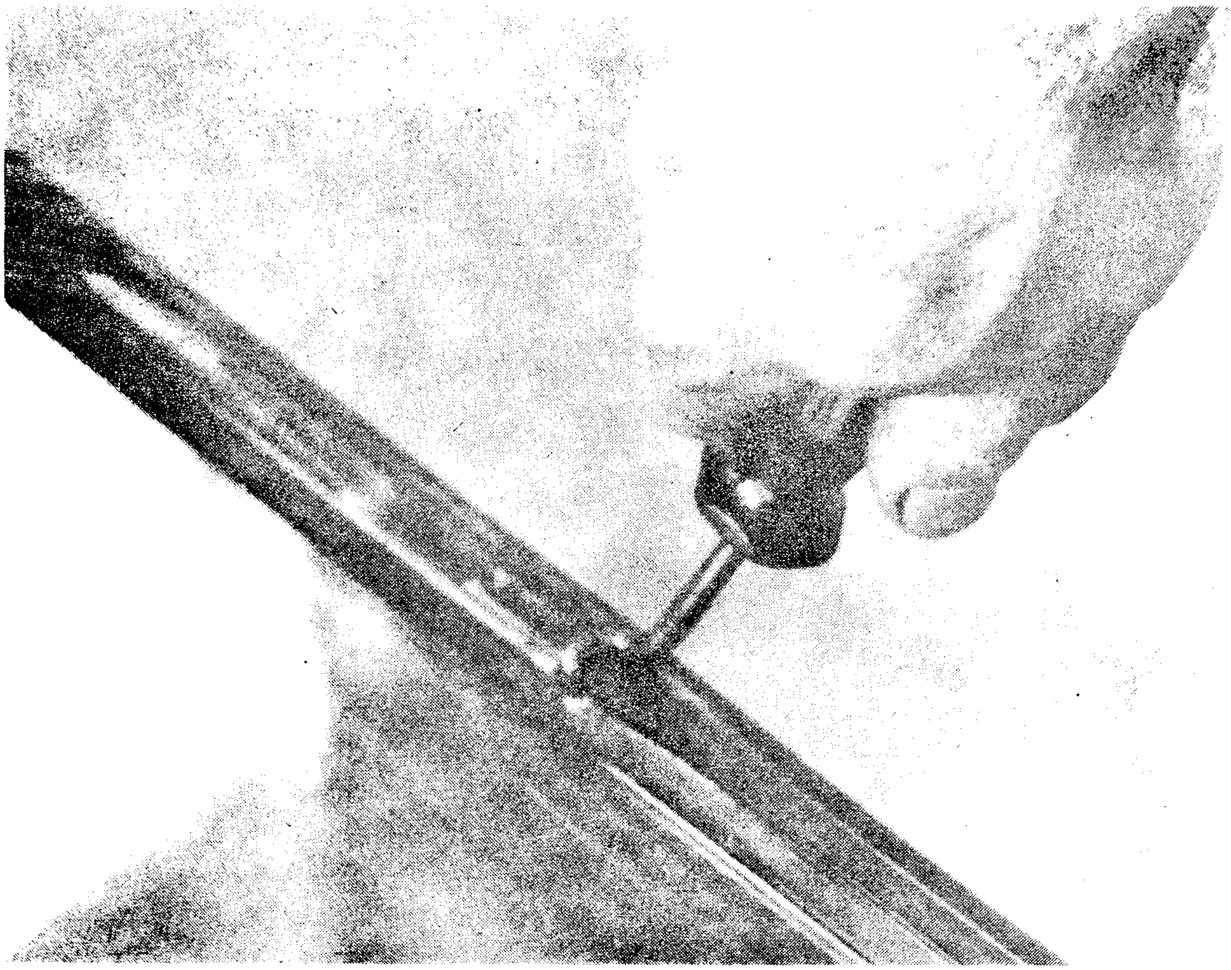
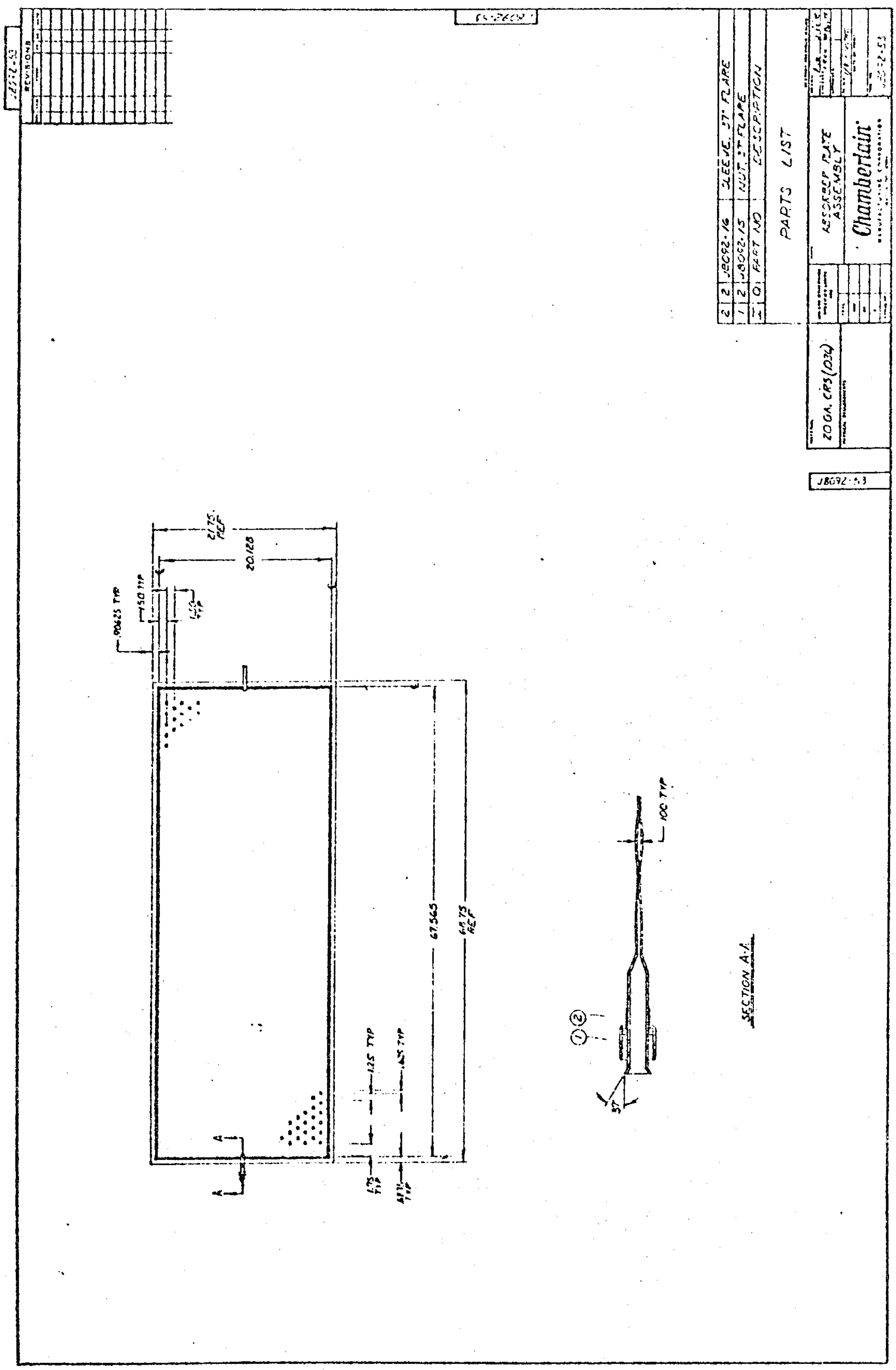


Figure 5. Engaging the Glazing Channel Locking Strip

area) over a 15-minute period..." Thus the efficiency of the collector is a direct function of the aperture area, as well as other defined parameters.

3.3 Absorber Plate

The absorber plates used in the prototype models of the solar collector are fabricated from 20-gage carbon steel as shown in Drawing No. J8092-53 on the following page. The plates are manufactured by Tranter Incorporated, Lansing, Michigan. The absorber plates use a stitch weld pattern for flow



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distribution. This results in a higher effective wetted area of the metal plate than could be obtained with a parallel passage unit which uses continuous seam welds for flow passage separation. This technique offers a higher operating efficiency due to the fact that the collected energy must pass only through the thickness of the plate to be transferred to the operating fluid. Since there is essentially no finned, unwetted area, the net plate heat transfer efficiency is higher than the parallel passage design made of the same material.

The absorber plates are formed in the following manner. Two sheets of 20-gage carbon steel material are seam welded around the perimeter with pressure tubes brazed in place at the inlet and outlet tube locations. The stitch welds are then formed using a resistance welder with controls to apply a uniform pattern. This typically is accomplished with a welder using multiple rollers on a uniform lateral distribution. The welded plates then are placed between platens to restrict the expansion heights to that required for the flow passages and manifold formation. Hydraulic pressure is applied which deforms the metal in a very uniform manner to develop the flow passage height and the inlet/outlet headers. The absorber plate then is ready for leak testing and coating application.

The optical coatings applied to the absorber plates are: black chrome over bright nickel and black copper over bright copper. Two collector modules are provided using the black chrome coating and one using the black copper. The black chrome coating is applied by Olympic Plating Industries, Canton, Ohio, and the black copper is applied by Enthone, Inc., New Haven, Connecticut.

Two types of coatings are provided because Chamberlain's cost effectiveness investigations, discussed in more detail later in this report, indicated

that the black copper coating would be slightly more cost effective. However, there were unanswered questions resulting from Chamberlain's investigation of the thermal degradation of the optical properties. This situation resulted in a reversal of the recommended coating to be used in this instance, and as such the black chrome is the first choice and black copper second. This result could possibly be negated by the findings of additional tests which Chamberlain is now awaiting. The black copper, if stable at stagnation temperatures, would be the most cost effective coating. The thermal degradation test results and field operation of the prototype units will provide the answers to this question.

3.4 Insulation

The insulation used in the collector module was the one component where possibly the largest number of choices were available. These included glass fibers, mineral/ceramic fibers, rigid foam and other miscellaneous types. All those considered are included in the Appendix. The final choice for use in the collector was a rigid foam insulation, and this was chosen because of three primary considerations: (1) the thermal characteristics which allowed the use of approximately 2/3 the thickness of others; (2) the additional rigidity the foam offered to the frame to aid in prevention of "racking;" and (3) the ability to automate the insulation application technique on an assembly line basis.

The thermal characteristics of the foam are somewhat dependent upon the application technique. On an assembly line basis, or for automated mixing techniques (frothing or spraying), the conductivity is in the 0.12-0.14 BTU-in./°F-hr-ft^2 range, but when poured from a hand-mixed system, the conductivity usually is of the order of 0.16-0.18 BTU-in./°F-hr-ft^2. This compares to a factor of about 0.24 for standard fiberglass insulations.

The formation of the foam insulation is accomplished by using a two-part mixture which, typically, has a very short reaction time. The preferred method for assembly line use is the frothing system. This unit mixes the two parts in the appropriate ratio, and the first of two rises occurs within the confinement of the applicator. The second rise of the mixture occurs within the frame or molding, whichever is used, and the final product is usually very uniform with little waste which would require trimming. The use of a spray gun, or multiple head sprayer if used in an automated sequence, mixes the two foam components externally. This usually occurs at the exit plane of the spray gun. The major disadvantages of this type of system include the percent wasted material and nonuniformity of the rising. This necessitates cutting the foam to remove the excess material. This procedure would require an additional process station on the assembly line.

Because of the limited number of prototypes delivered under this contract, a hand-pouring method was employed for applying the foam. The product used is manufactured by Witco Chemical, Wilmington, Delaware, and the trade name is Witco RC-3. In the hand-poured form it has a thermal conductivity of 0.16 BTU-in./hr-ft^2-°F.

In forming the insulation material, the frame side rails are assembled and coated with a mold release agent. The assembly then is placed over a form which becomes the cavity for the absorber plate assembly when removed. This form has a continuous sheet of 0.002 inch aluminum in place, which becomes the reflective shield over the top surface of the foam. The insulation components are mixed and then poured into the frame assembly. For this step, the complete unit is upside down, allowing the foam to be poured directly in place. Because of the characteristics of the foam, a limited pour time is available following the mix process. Due to the time restriction, only about two-foot lengths are poured at any one time. A barrier is used to prevent the insulation from spreading beyond this length. The prototype units required three pourings to complete the six-foot length. After

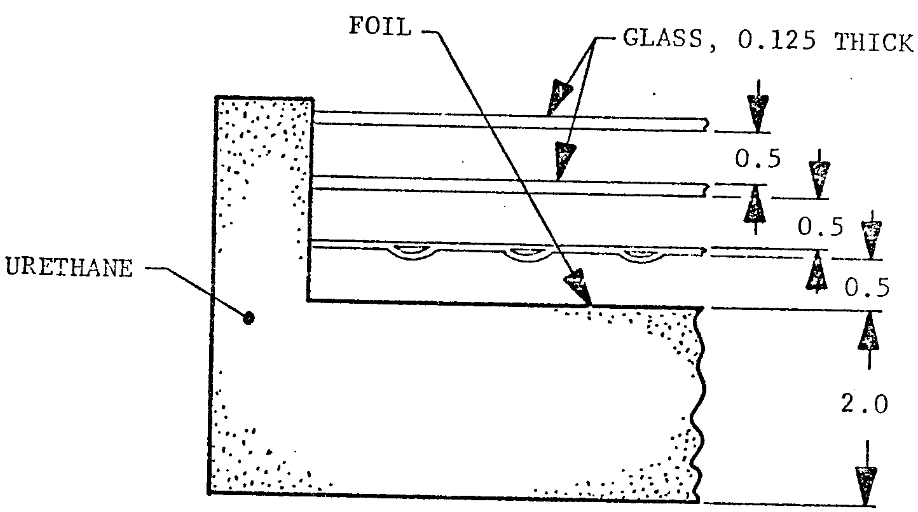
completing the pouring, and prior to removing the assembly from the form, the excess material is removed using a tool with a sharp edge which will span the two-foot dimension of the collector. This procedure completes the insulation application.

3.4.1 Edge Insulation Thickness

The Chamberlain Manufacturing Corporation solar collector simulation program was used to determine the optimum thickness of the edge insulation. The basic question to be answered is how thick the insulation can be made to reduce the edge losses, without reducing the net efficiency (based on collector gross area) of the collector under normal operating conditions. The National Bureau of Standards recommends that the efficiency of a solar collector be expressed in terms of aperture area, since this method of presentation will normally provide better correlation of the analytical predictions and the experimental results. For comparison of different flat plate collectors, it is felt that expressing the efficiency in terms of collector gross area is more meaningful since it is the gross area that is occupying the installation space and intercepting the solar insolation. Thus at Chamberlain, the collector efficiencies, both analytical and experimental, are based on the total collector area rather than just the cover opening (aperture).

The present investigation, then, was a trade-off of the edge losses and the total insolation intercepted by the absorber plate. The edge insulation thickness was increased in thickness steps to determine where the increase in this parameter caused the overall efficiency to begin to decrease. At that point, any increase in gross area for the purpose of increasing the edge insulation thickness would cause a net reduction in efficiency. If the efficiency were based on aperture area only, the edge insulation thickness would only have a major effect for extremely thin sections.

The simple edge loss model suggested by Duffie and Beckman in Solar Energy Thermal Processes was used in the simulation. The collector design is shown in Figure 6 below, and the results of the computer run are shown in Figure 7 on the following page. In determining the efficiency for an edge thickness equal to zero, it was assumed that the outside edge temperature was equal to the top cover temperature. This corresponds approximately to having no insulation except for a small thickness of rubber/metal. The efficiency versus edge insulation shown in Figure 7 indicates less than five percent change in efficiency for insulation thicknesses of 0.25-1.25 inches.



NOTE: All dimensions in inches.

Figure 6. Collector Design

3.5 Desiccant

The desiccant chosen to protect the collector's internal components from moisture is a silica gel product manufactured by Davison Chemical, Baltimore, Maryland. The physical characteristics of the canister containing the silica gel are: aluminum container, approximately 2.75 inches

March 10, Waterloo, Iowa
Noon, 36°F Ambient Temperature
10 mph Wind
Inlet Fluid Temperature 170°F
45° Collector Slope
45% Glycol Solution
Overall Panel = 2 ft. x 6 ft.
Insolation = 250 BTU/hr-ft^2

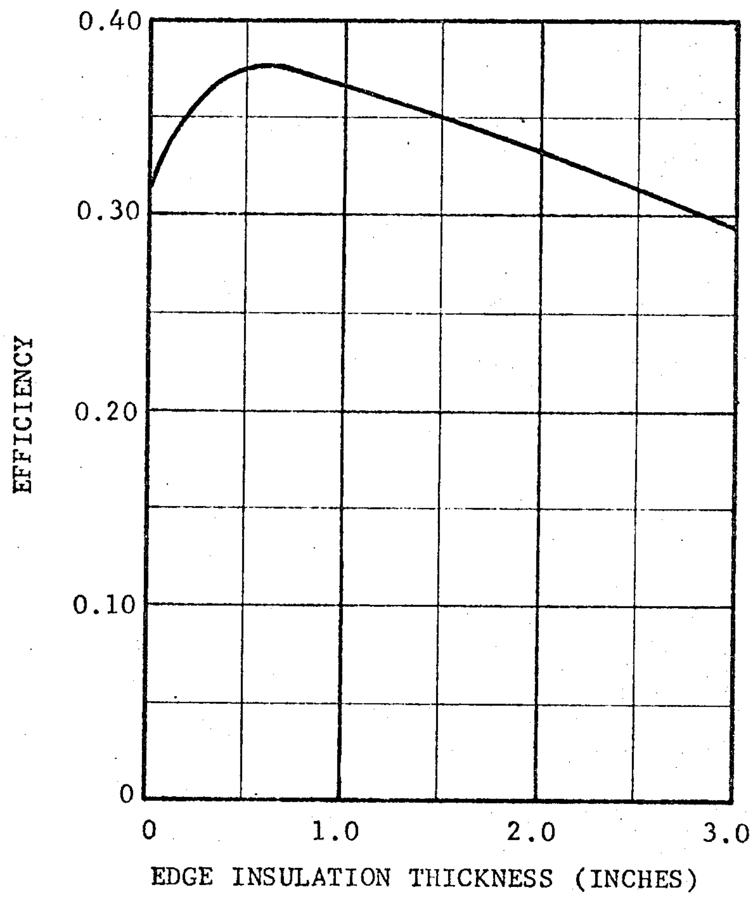


Figure 7. Results of Computer Run to Determine Optimum Thickness of Edge Insulation

in diameter and 0.6-inch high. Both top and bottom flat surfaces have many small perforations, approximately 0.025 inch in diameter, and uniformly distributed over the flat surface. These perforations promote the air infiltration through the silica gel. The desiccant canister is mounted in the geometric center of the foam insulation on the upper surface. The cutout in the foam results in a friction-fit to hold the canister in place. Tests of this system, including in-situ results, are discussed in the Appendix.

3.6 Sealant

The sealant used in the assembly of the prototype units is a standard silicone (one part) sealant with thermal limitations of -100 to +450°F. It is Dow Corning's Silastic 732. The silicone sealant was selected because of its thermal and weatherability properties. This sealant is 100 percent compatible with the materials with which it comes in contact. For a mass producible system, the glazing channel would not require a corner sealant since they would be continuous, molded pieces. For the prototypes fabricated under the subject contract it was necessary to cut the glazing channels from straight segments, requiring the silicone sealant be used at each corner.

3.7 Collector Assembly

Due to the fact that the collectors fabricated for this contract were prototypes, soft tooling was used. With only three units being made, hard tooling for fabrication was not justified. The prototypes also allow the determination of problem areas if they exist. Minor changes would be recommended for production of this collector on hard tooling, based on the assembly procedure followed on the prototypes.

As discussed in the insulation fabrication description, the foam/frame units were not fabricated as an integral unit. The absorber plate design required that the frame be removable for assembly purposes. The frame units, with

the foam in place, were received from the Monroe (Georgia) Division as one system. The frames were first removed from the foam by removing the sheet metal screws from the doubler assembly and the screws from the vapor barrier sheet on the bottom of the assembly. The absorber plate mounting blocks were allowed to remain attached to the end and side rails.

The absorber plate was first positioned with the inlet/outlet tubes projecting through the two end rails. This subassembly was then positioned over the foam insulation. One side rail was positioned for application of the sealant to the corner intersections, then, following the sealant application, was attached to the two end rails at the corners. Sheet metal screws are used for this purpose. The same procedure is used on the other side rail, completing the assembly of the framework. The unit is then covered on the bottom with a 26-gage galvanized, cold-rolled steel vapor barrier plate, which is necessary to meet code requirements and prevent moisture penetration. The plate is attached with sheet metal screws, following an application of sealant to the bottom surface of the frame and placement of the barrier plate. The unit then is sealed on the corners and bottom, and is ready for assembly of the glazing channel and cover plate.

The glazing channel is cut slightly longer (one to three percent longer) than the length necessary to fit the end or side rail, with 45° inside mitres at each end. This extra length insures that no separation will occur at the corners following complete assembly. Each cut piece of glazing channel is placed over the support "shoulder" of the top section of the frame, making certain that the channel is locked under the segment of frame which is turned to the inside of the collector assembly. With this step accomplished, the assembly is ready for installation of the glazing. A small bead of sealant is applied in a continuous strip to the channel where the glass will be inserted. The glass then is placed on top of the complete unit in preparation for glass assembly. A tool similar to a tongue depressor, but having more "body" and made from Teflon, is used to circumvent the perimeter of the glass by lifting the top section of the

glazing channel while simultaneously applying a slight pressure to the edge of the glass, the complete EPDM rubber channel may be assembled over the glass. The unit then is ready for locking in place following a positioning of the glass. Proper positioning of the glass is necessary because the unit is designed to have 0.090-0.100-inch space between the edge of the glass and the inside surface of the glazing channel at any point. If necessary, the entire unit may be tilted to either side to aid in sliding the glass to obtain this centering position. The glass is difficult to slide manually without the aid of suction cups used by glass handlers.

The locking strip of the glazing channel is lubricated for ease in obtaining the locked condition. The lubricant may be either water or a standard lubricant obtained from the glazing channel manufacturer. This standard lubricant solution evaporates quickly without residue and is slightly more effective than water. If available, it should be used. The lubricating solution used by Chamberlain was Stan Pro Lubricant manufactured by Standard Products Company, Chemical Products Division, Cleveland, Ohio. A special tool, also obtained through the Standard Products Company, was used for locking the strip in place which effectively places a restraining pressure on both the glass surface and the frame. The locking strip may be implaced by hand but is definitely more difficult to accomplish than with the special tool. The entire perimeter may be locked down in a matter of minutes. Sealant then is applied to each corner of the glazing channel to complete the water-tight seal.

The flare fittings used on the inlet/outlet tubes of the collector are 37° hydraulic fittings. Care should be exercised in making certain that these fittings are not connected to the standard refrigeration fittings, because they are typically 45° flare units. The system provided is for a standard hydraulic fitting.

A rubber grommet is placed over the inlet/outlet tubes and put in position on the frame assembly. This is followed by additional sealant at this joint.

The assembled collector is shown on the following page.

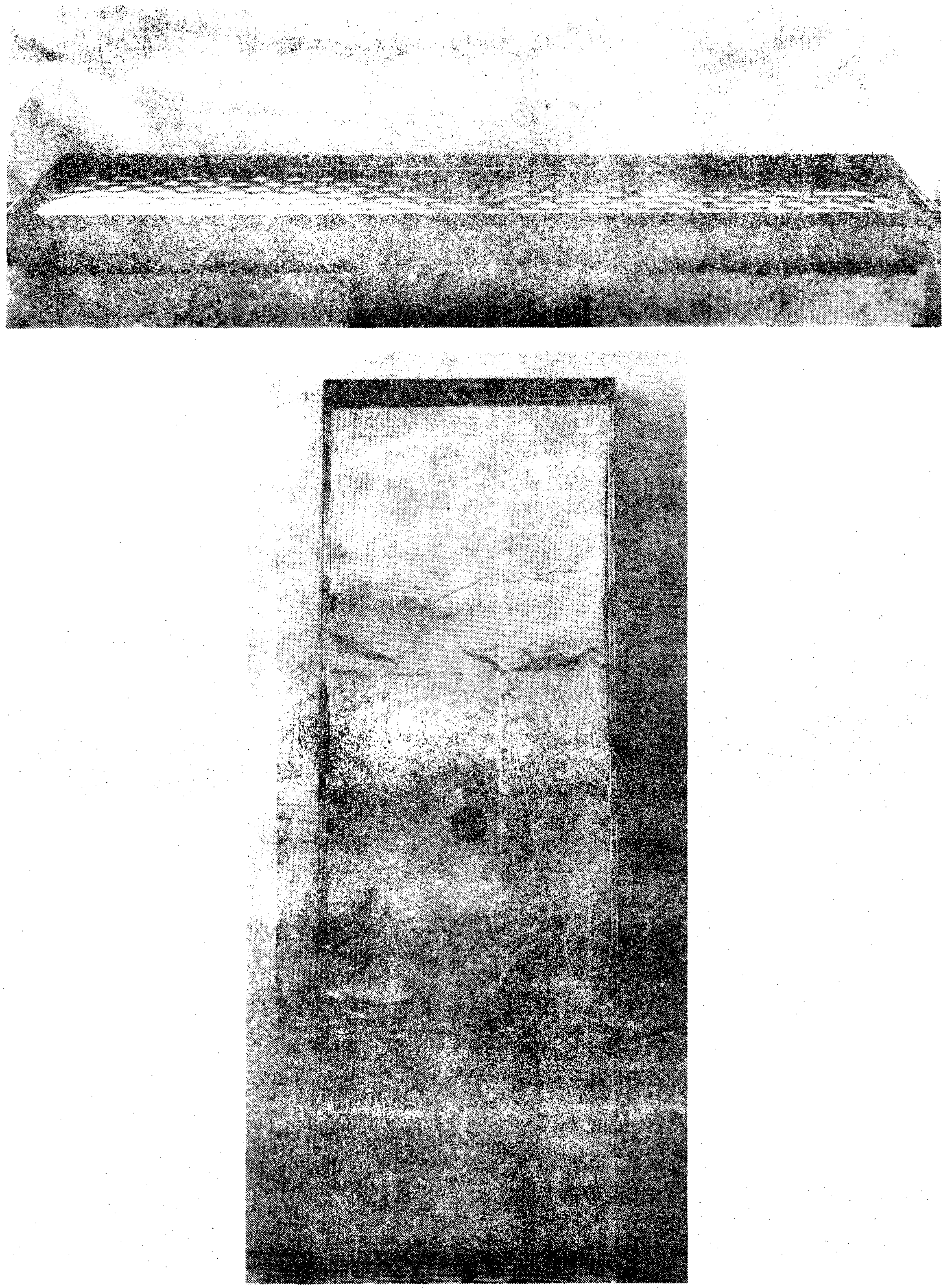


Figure 8. Assembly of Collector

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The complete collector is now prepared for shipment or installation. Mounting feet are provided for mounting purposes.

4. COLLECTOR PERFORMANCE/COST ANALYSIS

The question of what is the best collector, or most cost effective unit, is quite complex. In addition to basic collector cost, consideration must be given to many factors, such as application, locale, average insolation, operating temperatures and weather conditions. The effect of small changes in the absorber plate coating as a function of operating temperature and insolation can have reasonably large effects on the collector performance (see Appendix F, Effect of Changes in Absorptivity and Emissivity on Collector Performance).

The results shown in this section required assumptions which would not be made for a complete study on this subject. Further investigations should be made which were beyond the scope of this program. The most stringent assumption made was that a normally incident solar flux of 300 BTU/hr-ft^2 was available. Results are provided in Table 1 on the following four pages for both one- and two-cover collectors operating in summer (90°F) and winter (20°F) environments.

There are two means of comparing the performance of the collectors: (1) total energy gain per unit (BTU/hr-ft^2) and (2) energy gain per unit for collector cost per unit (BTU/hr-ft^2/\$/ft^2). If cost is not a major consideration, then the former parameter should be considered. For consumer purposes, cost must be assumed to be a major factor rather than minor. In this case the performance/cost parameter is that factor given major consideration. In the case of pure energy gain, Table 1 shows that the two-cover, black chrome collector using the ASG Water White glass would be the superior unit. When cost effectiveness is considered, the superior units would be the two-cover collectors having Fourco glass and either Caldwell paint or

TABLE 1. COMPARISON OF COLLECTORS' COST/PERFORMANCE PARAMETER

(Summer Operation)

Ambient Temperature = 90°F
Inlet Temperature = 210°F

Flow Rate = 0.576 gal/min
Wind Speed = 7.0 mph

Cover: Water White 1/8" Transmittance = 0.913
Water White 3/16" Transmittance = 0.91
Fourco 1/8" Transmittance = 0.906
Fourco 3/16" Transmittance = 0.90
Herculite K 1/8" Transmittance = 0.865
Herculite K 3/16" Transmittance = 0.84

Absorber: Black Chrome α/ε = .93/.08
Black Copper α/ε = .90/.12
Caldwell Paint #2 α/ε = .90/.58
Caldwell Paint #1 α/ε = .96/.88
3M Paint α/ε = .95/.95

No. of Covers	Insolation BTU/hr-ft^2	Glass Type	Coating Type	Energy Gain BTU/hr	BTU/hr-ft^2	BTU/hr-ft^2 / \$/ft^2
2	300	Water White 1/8"	Black Chrome	3,797	158.2	21.378
		Water White 3/16"	Black Chrome	3,763	156.8	20.632
		Fourco 1/8"	Black Chrome	3,725	155.2	25.953
		Fourco 3/16"	Black Chrome	3,656	152.3	25.132
		Herculite K 1/8"	Black Chrome	3,282	136.8	22.574
		Herculite K 3/16"	Black Chrome	3,016	125.7	20.209
2	300	Water White 1/8"	Black Copper	3,594	149.8	23.778
		Water White 3/16"	Black Copper	3,560	148.3	22.134
		Fourco 1/8"	Black Copper	3,524	146.8	28.898
		Fourco 3/16"	Black Copper	3,456	144.0	27.907
		Herculite K 1/8"	Black Copper	3,093	128.9	24.981
		Herculite K 3/16"	Black Copper	2,834	118.1	22.199
2	300	Water White 1/8"	3M Paint	2,905	121.0	20.862
		Water White 3/16"	3M Paint	2,871	119.6	19.290
		Fourco 1/8"	3M Paint	2,834	118.1	25.786
		Fourco 3/16"	3M Paint	2,767	115.3	24.742
		Herculite K 1/8"	3M Paint	2,401	100.0	21.459
		Herculite K 3/16"	3M Paint	2,140	89.2	18.506
2	300	Water White 1/8"	Caldwell Paint #1	2,991	124.6	22.092
		Water White 3/16"	Caldwell Paint #1	2,957	123.2	20.397
		Fourco 1/8"	Caldwell Paint #1	2,919	121.6	27.511
		Fourco 3/16"	Caldwell Paint #1	2,851	118.8	26.400
		Herculite K 1/8"	Caldwell Paint #1	2,482	103.4	22.978
		Herculite K 3/16"	Caldwell Paint #1	2,219	92.4	19.878
2	300	Water White 1/8"	Caldwell Paint #2	2,986	124.4	22.057
		Water White 3/16"	Caldwell Paint #2	2,953	123.0	20.364
		Fourco 1/8"	Caldwell Paint #2	2,917	121.5	27.489
		Fourco 3/16"	Caldwell Paint #2	2,852	118.8	26.400
		Herculite K 1/8"	Caldwell Paint #2	2,498	104.1	23.133
		Herculite K 3/16"	Caldwell Paint #2	2,244	93.5	20.064

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TABLE 1 (CONTINUED)

(Winter Operation)

Ambient Temperature = 20°F
Inlet Temperature = 150°F

Flow Rate = 0.576 gal/min
Wind Speed = 7.0 mph

Cover: Water White 1/8" Transmittance = 0.913
Water White 3/16" Transmittance = 0.91
Fourco 1/8" Transmittance = 0.906
Fourco 3/16" Transmittance = 0.90
Herculite K 1/8" Transmittance = 0.865
Herculite K 3/16" Transmittance = 0.84

Absorber: Black Chrome α/ε = .93/.08
Black Copper α/ε = .90/.12
Caldwell Paint #2 α/ε = .90/.58
Caldwell Paint #1 α/ε = .96/.83
3M Paint α/ε = .95/.95

No. of Covers	Insolation $\frac{BTU}{hr-ft^2}$	Glass Type	Coating Type	Energy Gain BTU/hr	$\frac{BTU}{hr-ft^2}$	$\frac{BTU/hr-ft^2}{\$/ft^2}$
2	300	Water White 1/8"	Black Chrome	3,761	156.7	21.176
		Water White 3/16"	Black Chrome	3,727	155.3	20.434
		Fourco 1/8"	Black Chrome	3,689	153.7	25.702
		Fourco 3/16"	Black Chrome	3,620	150.8	24.884
		Herculite K 1/8"	Black Chrome	3,245	135.2	22.310
		Herculite K 3/16"	Black Chrome	2,978	124.1	19.952
2	300	Water White 1/8"	Black Copper	3,579	149.1	23.667
		Water White 3/16"	Black Copper	3,545	147.7	21.955
		Fourco 1/8"	Black Copper	3,508	146.2	28.779
		Fourco 3/16"	Black Copper	3,441	143.4	27.791
		Herculite K 1/8"	Black Copper	3,077	128.2	28.845
		Herculite K 3/16"	Black Copper	2,817	117.4	22.068
2	300	Water White 1/8"	3M Paint	3,084	128.5	22.155
		Water White 3/16"	3M Paint	3,051	127.1	20.500
		Fourco 1/8"	3M Paint	3,013	125.5	27.402
		Fourco 3/16"	3M Paint	2,945	122.7	26.330
		Herculite K 1/8"	3M Paint	2,577	107.4	23.047
		Herculite K 3/16"	3M Paint	2,314	96.42	20.004
2	300	Water White 1/8"	Caldwell Paint #1	3,164	131.8	23.369
		Water White 3/16"	Caldwell Paint #1	3,130	130.4	21.589
		Fourco 1/8"	Caldwell Paint #1	3,092	128.8	29.140
		Fourco 3/16"	Caldwell Paint #1	3,024	126.0	28.000
		Herculite K 1/8"	Caldwell Paint #1	2,652	110.5	24.556
		Herculite K 3/16"	Caldwell Paint #1	2,386	99.42	21.335
2	300	Water White 1/8"	Caldwell Paint #2	3,115	129.8	23.014
		Water White 3/16"	Caldwell Paint #2	3,082	128.4	21.258
		Fourco 1/8"	Caldwell Paint #2	3,046	126.9	28.710
		Fourco 1/8"	Caldwell Paint #2	2,980	124.2	27.600
		Herculite K 1/8"	Caldwell Paint #2	2,624	109.3	24.289
		Herculite K 3/16"	Caldwell Paint #2	2,369	98.71	21.182

TABLE 1 (CONTINUED)

(Summer Operation)

Ambient Temperature = 90°F
Inlet Temperature = 210°F

Flow Rate = 0.576 gal/min
Wind Speed = 7.0 mph

Cover: Water White 1/8" Transmittance = 0.913
Water White 3/16" Transmittance = 0.91
Fourco 1/8" Transmittance = 0.906
Fourco 3/16" Transmittance = 0.90
Herculite K 1/8" Transmittance = 0.865
Herculite K 3/16" Transmittance = 0.84

Absorber: Black Chrome α/ε = .93/.08
Black Copper α/ε = .90/.12
Caldwell Paint #2 α/ε = .90/.58
Caldwell Paint #1 α/ε = .96/.88
3M Paint α/ε = .95/.95

No. of Covers	Insolation $\frac{BTU}{hr\text{-}ft^2}$	Glass Type	Coating Type	Energy Gain BTU/hr	$\frac{BTU}{hr\text{-}ft^2}$	$\frac{BTU/hr\text{-}ft^2}{\$/ft^2}$
1	300	Water White 1/8"	Black Chrome	3,350	139.6	22.516
		Water White 3/16"	Black Chrome	3,329	138.7	21.672
		Fourco 1/8"	Black Chrome	3,305	137.7	24.722
		Fourco 3/16"	Black Chrome	3,263	136.0	24.242
		Herculite K 1/8"	Black Chrome	3,024	126.0	22.420
		Herculite K 3/16"	Black Chrome	2,845	118.5	20.753
1	300	Water White 1/8"	Black Copper	3,081	128.4	24.276
		Water White 3/16"	Black Copper	3,060	127.5	23.182
		Fourco 1/8"	Black Copper	3,037	126.5	26.858
		Fourco 3/16"	Black Copper	2,995	124.8	26.385
		Herculite K 1/8"	Black Copper	2,761	115.0	24.262
		Herculite K 3/16"	Black Copper	2,585	107.7	22.391
1	300	Water White 1/8"	3M Paint	1,466	61.08	12.725
		Water White 3/16"	3M Paint	1,443	60.13	12.026
		Fourco 1/8"	3M Paint	1,417	59.04	14.091
		Fourco 3/16"	3M Paint	1,370	57.08	13.494
		Herculite K 1/8"	3M Paint	1,105	46.04	10.884
		Herculite K 3/16"	3M Paint	906	37.75	8.759
1	300	Water White 1/8"	Caldwell Paint #1	1,624	67.67	14.584
		Water White 3/16"	Caldwell Paint #1	1,600	66.67	13.775
		Fourco 1/8"	Caldwell Paint #1	1,575	55.63	16.285
		Fourco 3/16"	Caldwell Paint #1	1,527	63.63	15.634
		Herculite K 1/8"	Caldwell Paint #1	1,262	52.58	12.919
		Herculite K 3/16"	Caldwell Paint #1	1,063	44.29	10.672
1	300	Water White 1/8"	Caldwell Paint #2	1,913	79.71	17.179
		Water White 3/16"	Caldwell Paint #2	1,892	78.83	16.287
		Fourco 1/8"	Caldwell Paint #2	1,867	77.79	19.303
		Fourco 3/16"	Caldwell Paint #2	1,823	75.96	18.663
		Herculite K 1/8"	Caldwell Paint #2	1,575	65.63	16.125
		Herculite K 3/16"	Caldwell Paint #2	1,388	57.83	13.935

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TABLE 1 (CONTINUED)

(Winter Operation)

Ambient Temperature = 20°F
Inlet Temperature = 150°F

Flow Rate = 0.576 gal/min
Wind Speed = 7.0 mph

Cover: Water White 1/8" Transmittance = 0.913
Water White 3/16" Transmittance = 0.91
Fourco 1/8" Transmittance = 0.906
Fourco 3/16" Transmittance = 0.90
Herculite K 1/8" Transmittance = 0.865
Herculite K 3/16" Transmittance = 0.84

Absorber: Black Chrome α/ϵ = .93/.08
Black Copper α/ϵ = .90/.12
Caldwell Paint #2 α/ϵ = .90/.58
Caldwell Paint #1 α/ϵ = .96/.83
3M Paint α/ϵ = .95/.95

No. of Covers	Insolation BTU/hr-ft^2	Glass Type	Coating Type	Energy Gain BTU/hr	BTU/hr-ft^2	(BTU/hr-ft^2)/($/ft^2)
1	300	Water White 1/8"	Black Chrome	3,185	132.7	21.403
		Water White 3/16"	Black Chrome	3,164	131.8	20.594
		Fourco 1/8"	Black Chrome	3,140	130.8	23.483
		Fourco 3/16"	Black Chrome	3,097	129.0	22.995
		Herculite K 1/8"	Black Chrome	2,855	119.0	21.174
		Herculite K 3/16"	Black Chrome	2,673	111.4	19.510
1	300	Water White 1/8"	Black Copper	2,947	122.8	23.170
		Water White 3/16"	Black Copper	2,927	122.0	22.182
		Fourco 1/8"	Black Copper	2,903	121.0	25.690
		Fourco 3/16"	Black Copper	2,861	119.2	25.201
		Herculite K 1/8"	Black Copper	2,623	109.3	23.059
		Herculite K 3/16"	Black Copper	2,444	101.8	21.164
1	300	Water White 1/8"	3M Paint	1,705	71.04	14.800
		Water White 3/16"	3M Paint	1,682	70.08	14.016
		Fourco 1/8"	3M Paint	1,656	69.00	16.468
		Fourco 3/16"	3M Paint	1,609	67.04	15.849
		Herculite K 1/8"	3M Paint	1,345	56.05	13.251
		Herculite K 3/16"	3M Paint	1,147	47.79	11.088
1	300	Water White 1/8"	Caldwell Paint #1	1,845	76.88	16.569
		Water White 3/16"	Caldwell Paint #1	1,822	75.92	15.686
		Fourco 1/8"	Caldwell Paint #1	1,796	74.83	18.568
		Fourco 3/16"	Caldwell Paint #1	1,749	72.88	17.907
		Herculite K 1/8"	Caldwell Paint #1	1,485	61.88	15.204
		Herculite K 3/16"	Caldwell Paint #1	1,285	53.54	12.901
1	300	Water White 1/8"	Caldwell Paint #2	2,034	84.75	18.265
		Water White 3/16"	Caldwell Paint #2	2,012	83.83	17.320
		Fourco 1/8"	Caldwell Paint #2	1,988	82.83	20.553
		Fourco 3/16"	Caldwell Paint #2	1,943	80.96	19.892
		Herculite K 1/8"	Caldwell Paint #2	1,695	70.63	17.354
		Herculite K 3/16"	Caldwell Paint #2	1,507	62.79	15.130

black copper coatings. The obvious reasons for the differences in performance/cost choices would be the overriding cost factors of the black chrome coating and the Water-White type glass. The cost differences in these two items alone, for a two-cover collector, could be nearly three dollars per square foot, which is a significant difference. The point should be reiterated, though, that further analysis would be necessary to ascertain the net difference between the Caldwell paint unit and the black copper unit to make a firm decision on which is "best."

The results in Table 1 show that, for any other combination of materials, the Fourco, low iron glass is the most cost effective for the assumed conditions. A comparison of the cost effectiveness of only those collectors using Fourco glass is given in Table 2. These results show that, for summer operation the black copper unit is the more cost effective, and for winter operation the Caldwell paint unit is more cost effective. For the winter operation conditions the black copper unit is only 1.2 percent less effective than the Caldwell paint configuration for the assumed conditions, while being 4.8 percent more effective under summer conditions. The black copper unit would thus be more effective on a year-round basis.

The combined effect of convective losses from the collector and emittance of the absorber coating also can be seen from these results. The effect of adding the second cover is demonstrated vividly by comparing the values of energy gain for the painted absorbers.

The data generated for this comparison show that significant differences do exist for the assumed conditions. A more complete analysis would be recommended to account for changes in values of absorption and emittance as well as transient solar flux conditions. As mentioned earlier, the scope of this program would not allow such an extensive investigation.

TABLE 2. COMPARISON OF COST/PERFORMANCE PARAMETER USING FOURCO LOW IRON GLASS COVERS

	TEMPERATURES (Ambient/ Inlet)	NO. OF COVERS	INSOLATION BTU/hr-ft^2	GLASS TYPE	COATING TYPE	ENERGY GAIN BTU/hr	ENERGY GAIN BTU/hr-ft^2	COST EFFECTIVENESS $\frac{BTU/hr\text{-}ft^2}{\$/ft^2}$
Summer Operation	90/210	1	300	Fourco 1/8"	Black Chrome	3,305	137.7	24.722
	90/210	1	300	Fourco 1/8"	Black Copper	3,037	126.5	26.858
	90/210	1	300	Fourco 1/8"	3M Paint	1,417	59.04	14.091
	90/210	1	300	Fourco 1/8"	Caldwell #1	1,575	65.63	16.285
	90/210	1	300	Fourco 1/8"	Caldwell #2	1,867	77.79	19.303
	90/210	2	300	Fourco 1/8"	Black Chrome	3,725	155.2	25.953
	90/210	2	300	Fourco 1/8"	Black Copper	3,524	146.8	28.898
	90/210	2	300	Fourco 1/8"	3M Paint	2,834	118.1	25.786
	90/210	2	300	Fourco 1/8"	Caldwell #1	2,919	121.6	27.511
	90/210	2	300	Fourco 1/8"	Caldwell #2	2,917	121.5	27.489
Winter Operation	20/150	1	300	Fourco 1/8"	Black Chrome	3,140	130.8	23.483
	20/150	1	300	Fourco 1/8"	Black Copper	2,903	121.0	25.690
	20/150	1	300	Fourco 1/8"	3M Paint	1,656	69.0	16.468
	20/150	1	300	Fourco 1/8"	Caldwell #1	1,796	74.8	18.568
	20/150	1	300	Fourco 1/8"	Caldwell #2	1,988	82.8	20.553
	20/150	2	300	Fourco 1/8"	Black Chrome	3,689	153.7	25.702
	20/150	2	300	Fourco 1/8"	Black Copper	3,508	146.2	28.779
	20/150	2	300	Fourco 1/8"	3M Paint	3,013	125.5	27.402
	20/150	2	300	Fourco 1/8"	Caldwell #1	3,092	128.8	29.140
	20/150	2	300	Fourco 1/8"	Caldwell #2	3,046	126.9	28.710

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5. PROTOTYPE PERFORMANCE

Thermal performance testing of all three prototype collectors was accomplished prior to shipment of the units to NASA/MSFC. Because of the inconsistency of weather conditions, the results obtained were not as extensive as would have been desired. The period available for testing was nearly two months, but examination of the data tabulated in Table 3 shows lengths of time up to three weeks when the available solar insolation was insufficient to satisfy the NBS requirements for testing solar collectors.

Even with the limited number of test days available, an extremely wide range of test conditions was attained. The test conditions include temperature differences between fluid inlet and ambient temperatures as low as 16°F and as high as 183°F. The ambient temperatures range from a high of 66°F to a low of -9°F. Because of these wide variations in the test parameters, results for the black copper selective coating could not be obtained for low values of $(T_{inlet} - T_{ambient})/I$. For example, the last datum point tabulated was for 7 January 1976. The inlet temperature is shown to be 71°F. The ambient temperature was -1°F, giving a net difference between these temperatures of 72°F. In order to obtain data on the extreme low end of $(T_{inlet} - T_{ambient})/I$, these two temperatures must approach equality. Examine the data of 10 December 1975, 109°F inlet temperature. For an inlet temperature 37°F higher than the 7 January test point, the parameter $(T_{inlet} - T_{ambient})/I$ is actually lower. It is unfortunate that time and weather did not permit lower values to be obtained. Additional values of efficiency at these lower numbers would have been beneficial in defining the performance curve.

The results of the thermal performance testing are shown in Figure 9. As can be seen from this figure, the comparative performance of all three prototype collectors is exceptional, and the individual collector performance is excellent. The method of presentation is very similar to that

TABLE 3. EXPERIMENTAL CONDITIONS AND RESULTS OF NASA/MSFC FLAT PLATE COLLECTOR TESTS

DATE 1975/1976	TIME (CST)	WIND SPEED (mph)	WIND DIRECTION	T_{amb} (°F)	FLOW RATE AT °F (gpm)	FLOW RATE AT °F (°F)	T_{inlet} (°F)	Δt (°F)	I (BTU/hr-ft^2)	T_{in}-T_{amb}/I (hr-ft^2-°F/BTU)	EFFICIENCY	
28 Oct	11:20	4	NW	51	0.280	142	184	7.87	265.1	0.500	0.325	Black Chrome "A"
28 Oct	11:35	4	NW	52	0.280	142	195	7.12	266.2	0.536	0.295	
29 Oct	9:45	2	N	42	0.280	140	194	4.70	222.2	0.682	0.233	
29 Oct	10:35	2	N	47	0.280	140	195	7.27	253.7	0.582	0.316	
29 Oct	11:47	5	S	48	0.276	92	140	13.07	269.1	0.341	0.519	
29 Oct	1:22	3	W	53	0.274	73	76	16.63	246.4	0.093	0.695	
29 Oct	1:53	4	W	54	0.274	73	76	15.81	232.3	0.094	0.701	
10 Nov	11:40	10	SW	50	0.277	146	193	6.87	266.2	0.536	0.284	
10 Nov	1:00	10	SW	52	0.278	145	194	6.89	261.8	0.541	0.290	
10 Nov	2:00	12	SW	53	0.276	103	161	7.20	229.9	0.468	0.339	
17 Nov	10:10	14	S	58	0.275	72	79	13.05	204.6	0.102	0.658	Black Chrome "B"
17 Nov	11:50	11	S	64	0.275	73	80	16.08	242.0	0.066	0.686	
17 Nov	1:00	9	S	65	0.277	101	160	8.05	224.4	0.422	0.388	
17 Nov	1:35	9	S	66	0.277	101	159	6.60	201.3	0.461	0.354	
10 Dec	12:45	8	SW	46	0.275	90	109	11.30	229.9	0.273	0.516	Black Copper
10 Dec	1:50	7	SW	48	0.274	93	120	8.00	198.0	0.363	0.427	
17 Dec	11:00	10	N	3	0.274	83	109	9.73	246.4	0.429	0.414	
17 Dec	12:30	5	N	7	0.274	84	110	10.09	253.0	0.406	0.419	
18 Dec	11:30	10	N	8	0.274	86	112	10.76	259.6	0.400	0.436	
18 Dec	1:00	7	N	11	0.274	86	112	10.46	250.8	0.402	0.438	
7 Jan	11:00	15	N	-9	0.273	108	173	1.12	246.4	0.737	0.049	
7 Jan	11:40	12	N	-9	0.274	108	174	2.84	259.6	0.703	0.119	
7 Jan	1:00	15	N	-4	0.283	91	132	7.57	257.4	0.527	0.313	
7 Jan	2:00	15	N	-1	0.274	66	71	11.75	224.4	0.320	0.537	

NASA/MSFC Flat Plate Solar Collectors
Single Glass Cover - Fourco Cleartemp®, 3/16-Inch
Gross Dimensions: 70.25 x 23.25 inches
Aperture Dimensions: 68.50 x 21.50 inches

Tilt Angle Facing Due South: 39° (Black Chrome "A")
48° (Black Chrome "B")
48° (Black Copper)

Efficiency Based on Gross Area

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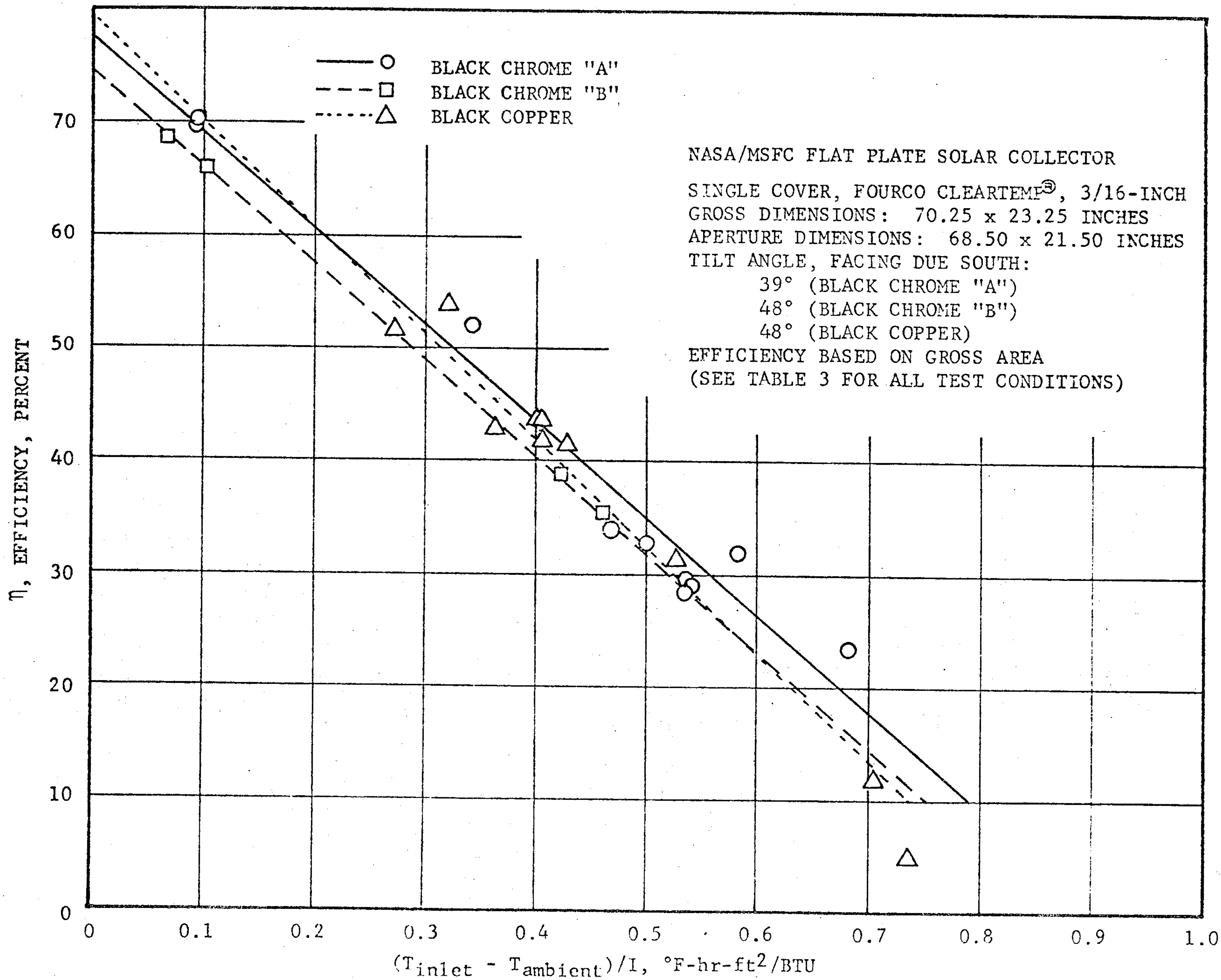

Figure 9. Results of Thermal Performance Testing of Prototype Collectors

used in NBSIR 74-635, "Method of Testing for Rating Solar Collectors Based on Thermal Performance." The differences between the methods are very minor. In the definition of collector efficiency, NBS recommends the following:

$$\eta = \dot{m}\, C_p\, \Delta t / I\, A_{aperture},$$

where:

η = efficiency (dimensionless)

$\dot{m}$ = mass flow rate (lb_m/hr)

Δt = temperature rise across collector (°F)

I = insolation rate (BTU/hr-ft^2)

$A_{aperture}$ = collector aperture area (ft^2)

C_p = specific heat of transfer fluid (BTU/lb_m-°F)

As mentioned earlier in Section 3 of this report, personnel at Chamberlain are concerned that a true comparison of various collectors cannot be made on the basis of collector efficiency based on aperture area since the gross area of the collector is the true area intercepting the solar flux and occupying the installation space. Chamberlain prefers to define the efficiency as:

$$\eta = \dot{m}\, C_p\, \Delta t / I\, A_{gross},$$

where all terms with the exception of A_{gross} are the same as in the previous equation. The term A_{gross} is the gross area of the collector at its largest dimensions, whether those dimensions occur on the cover or base frame. On the NASA/MSFC solar collectors, the gross area is found from the outside dimensions of the EPDM glazing channel since it extends beyond the frame side/end rails.

The parameter used for the abscissa of Figure 9, $(T_{inlet} - T_{ambient})/I$, is only a convenience modification of the parameter recommended by the NBS. In their recommended methods, this parameter is given as:

$$(\overline{T}_{fluid} - T_{ambient})/I$$

where $\overline{T}_{fluid}$ = average fluid temperature $= (T_{inlet} + T_{outlet})/2$

The question of what these differences mean in the way of data presentation is often asked. In effect, the results simply shift on the scales as presented in Figure 9. For example, assume the following:

$$\begin{aligned}
\dot{m} &= 120\ lb_m/hr \\
C_p &= 0.9\ BTU/lb_m\text{-}^\circ F \\
\Delta t &= 12.0^\circ F \\
I &= 250\ BTU/hr\text{-}ft^2 \\
A_{aperture} &= 22.8\ ft^2 \\
A_{gross} &= 24\ ft^2 \\
T_{inlet} &= 150^\circ F \\
T_{ambient} &= 90^\circ F
\end{aligned}$$

Then, for the NBS method of data presentation,

$$\eta = \dot{m}\ C_p\ \Delta t/I\ A_{aperture} = 22.7\%$$

and for the Chamberlain method,

$$\eta = \dot{m}\ C_p\ \Delta t/I\ A_{gross} = 21.6\%$$

For the abscissa parameter, the NBS method would result in

$$\left(\frac{T_{inlet} + T_{outlet}}{2} - T_{ambient}\right)/I = 0.264$$

and the Chamberlain method would give

$$(T_{inlet} - T_{ambient})/I = 0.240$$

so both parameters presently used by Chamberlain for data presentation result in lower values of the two pertinent parameters, albeit small. Thus, if Figure 9 is considered, the results shown will be shifted slightly upward and to the right if the results were converted to NBS parameters. Therefore, for comparison of the present data with other solar collector performance curves, these facts must be considered.

One additional parameter sometimes used for "quickie" collector performance comparisons is the product of glazing transmissivity and absorptivity of the selective coating. To do this, the implicit assumption is made that the efficiency is based on aperture area, which is not the case for the data presented here. An additional factor of the ratio of aperture area divided by the gross area must be introduced for comparison purposes. For example, the $\tau\alpha$ product for the black chrome collector would be approximately 0.846. Introducing the area ratio $A_{aperture}/A_{gross} = 0.902$ reduces the no-loss efficiency value at ambient temperature to 0.762 instead of the 0.846 value.

In Figure 9, the ordinate intercept of the black chrome models are 0.744 and 0.774. These values are within -2.4, +1.6 percent of the simple $\tau\alpha\ A_{aperture}/A_{gross}$ product. However, the black copper model is not in agreement as well. This particular inequality has been found in several collectors; Chamberlain's as well as other manufacturers. For example, the $\tau\alpha\ (A_{aperture}/A_{gross})$ product for the black copper model is 0.721, but the least squares projection of the ordinate intercept occurs at 0.792, or +9.8 percent. The absorptivity/emissivity characteristics of the black copper are 0.90/0.12, while the black chrome is 0.95/0.17. This would infer that, for ambient operating conditions, the black chrome collector should operate at an efficiency approximately 5 percent higher than the black copper, which the experimental results indicate is not the case.

The slope of the representative least squares fit of the data represent the losses of the collector. As is evident from the performance curve, the black copper model apparently has slightly higher losses than either black chrome data set would indicate for these collectors. The black chrome models are in excellent agreement with each other as far as the losses are concerned. This characteristic of higher losses on the black copper model are typical of what has been found in the past for collectors which indicated higher efficiencies than theoretically possible at ambient conditions. Examination of the least squares data fit for the black copper model shows that if the ordinate intercept value was closer to 0.721 as was anticipated, and the high temperature data points were to remain the same, then the losses of the black copper unit essentially would be identical to the black chrome units. There is no reason why the losses on one model should be significantly different from any other.

The test data provided in Table 3 showed that the test conditions for the black copper model were extreme, with the exception of the solar insolation. The first two data points, obtained for an ambient temperature of 46-48°F, are both below the least squares data fit. The character of the data fit is dictated by the remaining eight datum points, with an average ambient temperature of only three degrees above zero and an average wind velocity of nearly 12 mph.

Overall, the performance of all three collectors was extremely good, and the agreement of the data for the two different types - black chrome and black copper - were exceptional. The collectors have to be considered high performance units, showing efficiencies of approximately 10 percent even when operating at temperatures 180°F above ambient. For a flat plate solar collector with only one cover, 180°F above ambient is an extremely high operating temperature, especially considering that the wind velocity was nearly 15 mph. If consideration is given to a typical Huntsville, Alabama winter condition of 20°F ambient and 140°F inlet temperature, with an insolation value of 275 BTU/hr-ft^2, the collectors would be expected to

operate in the range of 35 percent efficiency. For summer cooling, 90°F ambient, 200°F inlet temperature and 250 BTU/hr-ft^2 insolation, one could anticipate efficiencies of approximately 37-38 percent. These are very reasonable figures for a high performance collector.

6. COLLECTOR QUANTITY PRODUCTION

The production cost of the 3 foot by 8 foot collector, having a single cover and a black copper absorber coating is presented. The fabrication costs as projected are for a quantity of units totaling a minimum of 10,000 square feet. A tooling cost, not included in the production cost of the collectors, is provided for information purposes. The tooling cost is not included because a production run of 10,000 square feet is not considered to be of sufficient volume to justify hard tooling for a one-time production run. For example, on a 10,000 square foot production run, the total cost (for production) would be $102,500 if the tooling is not amortized over that quantity. If it were included, the cost would rise to nearly $110,000 or an increase of about $.70 per square foot. For a production run of, say, 250,000 square feet, which is a reasonable production run check-out volume, the hard tooling could be amortized more reasonably. The total cost would approach 2.57 x 10^6 dollars, or only 0.2 percent in excess of the production cost of the collectors. The typical hard tooling amortization period is generally of such longevity that the production run of that product will be sufficient to preclude a major impact on the production cost of that item.

The parts list breakdown of the collector and the associated material weight, material cost, purchase cost and labor hours, together with the estimated tooling cost, is provided in Table 4 on the following page. The summary figures, including raw material, scrap and shrinkage and labor hours are presented at the end of Table 4. The final summary figure of $246.00 is the per unit cost on a quantity basis.

TABLE 4. COLLECTOR UNIT COST BREAKDOWN

PART OR DESCRIPTION	REFERENCE DRAWING	NUMBER REQUIRED	WEIGHT (Lbs.)	MATERIAL UNIT COST	MATERIAL COST	PURCHASE COST	LABOR HOURS	TOOLING COSTS
Absorber Plate	J8092-53	1	71.6	-	-	69.26	0.0333	-
Frame Top	J8092-83	1	5.574	18.03/cwt	0.5025	-	0.150	1,815
Frame Bottom	J8092-83	1	5.574	18.03/cwt	0.5025	-	0.150	-
Frame Side	J8092-82	2	14.24	18.03/cwt	2.680	-	0.300	-
Pop Rivets	J8092-25	12	0.12	0.02 ea.	-	0.240	-	-
Angle	J8092-27	4	0.372	17.51/cwt	0.065	-	0.0341	3,388
Rivnut	J8092-85	8	0.12	0.124 ea.	-	0.992	-	-
Glass	J8092-29	1	40.2	0.42/ft^2	-	9.740	-	-
Seal, Glass, Sides	J8092-30	2	-	0.0607/ft	-	0.971	-	-
Seal, Glass, Top/Bottom	J8092-30	1	-	0.0607/ft	-	0.364	-	-
Reflector, Aluminum	J8092-31	1	-	0.90/1b	-	0.648	-	-
Pan, Barrier	J8092-33	1	20.17	20.14/cwt	4.072	-	0.0844	242
Caulk	J8092-35	As Required	-	0.208/ft	-	0.270	0.0260	-
Screws (Phenolic Block)	J8092-74	10	-	0.015 ea.	-	0.150	-	-
Screws (Barrier Pan)	J8092-74	26	-	0.015 ea.	-	0.390	-	-
Insulation, Foam	J8092-37	As Required	16.0	0.32/bd ft	-	16.000	0.1667	-
Support, Absorber Plate	J8092-86	10	-	0.146/cu in	-	0.819	0.2227	-
Grommet	J8092-40	2	-	0.058 ea.	-	0.116	-	-
Desiccant	J8092-84	1	0.24	0.880 ea.	-	0.880	0.0223	-
Frame Subassembly	J8092-81	1	-	-	-	-	0.5333	241
Doubler Assembly	J8092-26	4	-	-	-	-	0.0891	-
Foam Installation	-	1	-	-	-	-	0.1667	-
Absorber Installation	-	1	-	-	-	-	0.5333	-
Packaging	-	1	-	-	-	2.000	0.2223	-
Glass Installation	-	1	-	-	-	-	0.8889	-
Miscellaneous Tooling	-	-	-	-	-	-	-	1,210
Absorber Backside Paint	-	-	-	-	0.395	-	0.1667	-
Absorber Plating	-	As Required	-	0.75/ft^2	-	17.358	-	-
Caulk	J8092-39	As Required	-	8.40/gal	-	0.168	-	-
SUBTOTAL			174.21		8.217	120.366	3.7898	6,896

BLACK COPPER COLLECTOR COST SUMMARY SHEET

Material Summary	
Raw Material	$ 8.217
Purchased Material	120.366
Scrap and Shrinkage	6.427
Subtotal	$135.010
Labor Summary	
Direct Labor	3.7898 hours
Indirect Labor	1.8934 hours
Subtotal	5.6832 hours
Cost of Labor, Overhead, G&A and Fee	$110.99
Total Quantity Per Unit Cost	$246.00 or $10.25/ft^2

NOTE: An additional one-time hard tooling charge of $6,896.00 is applicable to the quantity pricing schedule.

All pricing schedules shown are for products FOB Monroe, Georgia.

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6. QUANTITY PRODUCTION

The costs shown in Table 4, and in particular the summary figures, are those costs associated with a direct procurement of at least 75 units, or 1,800 square feet of collectors. The one-time hard tooling charge would be applicable to a procurement of this magnitude or larger. Any procurement smaller in number would have different fabrication costs associated with the smaller numbers.

The production cost of the black copper unit is competitive with figures quoted by other investigators. The real cost analysis, though, should be on a basis of the collector performance/cost parameter, (BTU/hr-ft^2/($/ft^2). Since the black copper unit is performance/cost competitive when compared to the other units investigated in this program, this is the only breakdown provided.

A review of the component costs of the black copper collector reveal several areas where cost improvement could be shown without any reduction in performance. For example, the purchase cost of the absorber plate is presently $69.26 each, including the flare fittings and shipping charges (from absorber manufacturer, plater and then to Monroe, Georgia), plus labor for applying the flare fittings. If Chamberlain were to manufacture the plates in Monroe, the overall price would probably be reduced, but the shipping charges would be partially offsetting since the present manufacturer and plater are nearer one another than Monroe. However, should Chamberlain establish a coating process line, this would have a treble effect: (1) reduction in plate manufacturing cost, (2) reduction in plating cost, and (3) elimination of shipping charges. No estimate presently is available for the total effect of a change such as this, but the shipping charges alone would represent approximately $0.50 per square foot. A total reduction in excess of $1.00 per square foot would not be unreasonable to expect. The capital expenditure to establish this capability would be extremely large.

An interesting aspect of the production of the collectors is a review of the items necessary for preparation of the product for shipment. For shipping purposes, the collectors would be palletized in units of eight collectors per pallet, with the collectors placed on their edges for banding and placement on the pallets. Efforts usually are made to make sure items containing spans of glass as large as those used in the collector are never shipped flat, but on edge. A carton then would be placed around the collectors/pallet package for shipment. An itemized list of the materials is as follows.

Pallet
Carton
Glass Protector
Tape
Banding
Label
Tube Plugs
Steel Band
Corner Protectors
Steel Band Seals
Separator Plate

7. CONCLUSIONS

The flat plate solar collector developed under Contract NAS8-31326 is an effective, high performance unit with a projected fabrication cost which places it in a low cost category. The fact was established early in the

program that the cost of a solar collector should not be based solely on the dollar cost of the unit, but a performance/cost criteria should be used. The parameter used by Chamberlain for these purposes was (BTU/hr-ft^2)/($/ft^2). This parameter provides the necessary criteria for evaluation of various collectors when the operating parameters (temperatures, primarily) are equivalent.

Many candidate materials were evaluated for their cost-effectiveness. The assumption was made in some cases (e.g., the glass cover) that mechanical and lifetime properties were the overriding evaluation criteria, while in some cases (insulation) the building code acceptability was the major criteria. When there was a choice of materials available for evaluation on a cost-effectiveness basis, that material providing the best performance per unit cost was selected. In the case of the selective coating applied to the steel absorber plate, the most cost-effective material was found to be black copper over bright copper, but due to unknowns in the thermal limitations of this selective coating, the recommendation was made that black chrome over bright nickel be the primary choice on the coating. As a result, two collectors were fabricated using a black chrome coating and one was made using black copper. All three units were tested at Chamberlain prior to shipment to NASA/MSFC.

The unique characteristic of these flat plate solar collectors is the glazing channel used for holding and sealing the glass cover plate to the galvanized side rail frames. The glazing channel is similar in function to the seals used for many years in heavy industry vehicle windshield sealing and in large span glass installations, such as in airports. The seal has a long history for effective sealing. The seal design also accounts for the possibility of wind loads creating a lifting force on the glass. The seal "locks" to the galvanized side rail frames to prevent uplift of the glass from occurring. The top/cover seal design also eliminates the metal cover requirements and the sealing gasket between the cover and basic frame as is found in most solar collectors. This feature aids in cost reduction through both materials and labor.

7. CONCLUSIONS

The thermal performance of the collectors showed that the unit is a high efficiency unit in both the black chrome and black copper selective coating models. Only the single cover collector design was fabricated because of the thermal performance requirements as stipulated in the contract. The unit was to provide the necessary temperature (200-210°F) to drive an absorption refrigeration system when located in the Huntsville, Alabama region. The collectors were found to operate in the 35-40 percent efficiency range for a 90°F ambient and 200°F inlet temperature, based on the thermal performance characteristics according to the National Bureau of Standards recommended procedure.

The solar collector design is compatible with the capabilities of most light gage metal roll-forming organizations, including Chamberlain. The 2 foot by 6 foot prototype models were fabricated at the Monroe (Georgia) Division of Chamberlain Manufacturing Corporation.

The collector uses a 20-gage, steel absorber plate which has flow passages formed hydraulically following an edge seam-welding and plate center stitch-welding process. The stitch-weld is applied in a staggered manner to form a "quilted" pattern. This pattern results in a more uniform flow than parallel seam-welds would provide. The wetted surface area of the plate is greater than 90 percent.

The collector resulting from this development program is a very cost-effective subsystem. Its thermal performance is quite good and the fabrication costs are relatively low, resulting in a unit with a very high performance per unit cost rating. A full-scale production program for this collector should provide a highly competitive product.

8. RECOMMENDATIONS

Several areas of collector design were found during the course of fabrication, assembly and performance evaluation which could possibly provide a lower fabrication cost and easier maintenance or assembly. There were no thermal performance shortcomings found.

One of the most troublesome and time consuming items found was the requirement for removal of three of the side rails to remove the absorber plate. A refinement of the absorber plate/inlet-outlet tube design would allow:

- Assembly or removal of the absorber plate from the top without dismantling the frame side rails.
- All expansion/contraction characteristics of the absorber plate to occur inside the collector, eliminating expansion tubes between the collector and distribution manifold.
- Simplification of the absorber plate mounting system.
- Fabrication/assembly of the frame side rails as either one or two pieces as opposed to the presently used four pieces.
- Flush mounting the inlet and outlet tubes so that there are no projections from the collector housing during shipment.

Each of these items would tend to reduce the overall cost of manufacturing the collector, with the possible exception of the flush mount consideration associated with the inlet/outlet tubes. This concept should be investigated to determine the most cost effective manner of achieving this end goal.

The capability to remove the absorber plate assembly from the housing without disturbing the side rails could be important. A desirable feature would be to allow this procedure without having to completely remove the collector

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from the array. Since the collectors are designed to effectively allow zero clearance between adjacent collectors, removal of the complete collector from an array would be a disadvantage. Another desirable feature would be a method whereby collectors placed in series could also be mounted with an effective zero clearance between any two north-south running assemblies. This would probably require the incorporation of some type quick-disconnect fitting, and would necessitate a cost effectiveness evaluation because of the additional hardware.

Elimination of an expansion tube between the collector and the distribution manifold would be a cost saving installation feature. The necessity of using either preformed or formed-on-site tubes to allow for the expansion/contraction characteristics of the absorber plate is now required by practically all collectors. By incorporating a tube with a female pipe fitting on the frame end of the inlet/outlet tube, all absorber plate movement can be contained within the collector housing. The cost of this flush mount fitting may be prohibitive.

A simplified absorber-mounting scheme, or simply a two-piece phenolic block should be investigated to allow vertical removal of the plate. This was not necessary on the present design since the side rails were removable.

By making the absorber plate removable from the top of the collector, the side rails could be roll-formed, cut and mitred at the proper points on an automated basis. The side rails could actually be formed from a single piece of metal and joined at the flush mount point of the inlet/outlet tubes. This feature would eliminate all corner caulking on the frame. The glazing channel then can be molded as a single piece to eliminate corner sealing on that piece. These two items basically would eliminate potential leak points and provide much longer leak-proof lifetimes.

Finally, the NASA/MSFC flat plate solar collector should be certified for operation according to both NASA and HUD Interim Performance Criteria for

commercial and residential applications. The qualification and certification of the collector from both operational and safety characteristics would be accomplished in compliance with these requirements. The program for qualification of the collector is quite extensive but is necessary for the collectors to be considered for use in the NASA/ERDA solar demonstration program.

REFERENCES

1. "Interim Performance Criteria for Commercial Solar Heating and Combined Heating/Cooling Systems and Facilities," Document No. 98M10001, February 28, 1975, George C. Marshall Space Flight Center, National Aeronautics and Space Administration.

2. Hill, J. E. and T. Kusuda, "Method of Testing for Rating Solar Collectors Based on Thermal Performance," NBSIR 74-635, prepared by the National Bureau of Standards for the National Science Foundation, December 1974.

APPENDIX A

GLAZINGS

A-1

GLAZING

MATERIAL	Cleartemp® Safety Glass
SOURCE	Fourco Glass Company, P.O. Box 2230, Clarksburg, West Virginia 26301, (304) 624-7504
TRANSMISSIVITY	89.8% of total solar energy, normal incidence
THICKNESS	1/8-inch Nominal
IRON CONTENT	.059% (Harding Division)
DEFLECTION UNDER LOAD	
LIFE EXPECTANCY	Over 20 Years
COST	Standard Sizes - \$.38/ft^2 Non-Standard Sizes - \$.39/ft^2

GLAZING

MATERIAL	Cleartemp® Safety Glass
SOURCE	Fourco Glass Company, P.O. Box 2230 Clarksburg, West Virginia 26301, (304) 624-7504
TRANSMISSIVITY	87.8% of total solar energy, normal incidence
THICKNESS	3/16-inch Nominal
IRON CONTENT	.059% (Harding Division)
DEFLECTION UNDER LOAD	
LIFE EXPECTANCY	Over 20 years
COST	$.43/ft^2

GLAZING

MATERIAL	Clearlite® Sheet Glass
SOURCE	Fourco Glass Company, P.O. Box 2230, Clarksburg, West Virginia 26301 (304-624-7504)
TRANSMISSIVITY	89.8% of total solar energy, normal incidence
THICKNESS	1/8-inch Nominal
IRON CONTENT	0.059% (Harding Division)
DEFLECTION UNDER LOAD	
LIFE EXPECTANCY	Over 20 Years
COST	~ $\$.25/ft^2$ Standard Sizes

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GLAZING

MATERIAL	Clearlite® Sheet Glass
SOURCE	Fourco Glass Company, P.O. Box 2230, Clarksburg, West Virginia 26301 (304-624-7504)
TRANSMISSIVITY	87.8% of total solar energy, normal incidence
THICKNESS	3/16-inch Nominal
IRON CONTENT	0.059% (Harding Division)
DEFLECTION UNDER LOAD	
LIFE EXPECTANCY	Over 20 Years
COST	$\$.32/ft^2$

GLAZING

MATERIAL	Tempered Glass - Crystal 76 Water-White
SOURCE	ASG Industries, P.O. Box 929, Kingsport, Tennessee 37662 (615) 245-0211
TRANSMISSIVITY	90.5% of total solar energy, normal incidence
THICKNESS	3/16-inch nominal (.175-.195)
IRON CONTENT	.000%
DEFLECTION UNDER LOAD	
LIFE EXPECTANCY	Over 20 years
COST	34" x 96" - 1.03/ft^2 34-5/8" x 94-5/8" - 1.41/ft^2

GLAZING

MATERIAL	Tempered Glass - Crystal 76 Water-White
SOURCE	ASG Industries, P.O. Box 929, Kingsport, Tennessee 37662 (615) 245-0211
TRANSMISSIVITY	91% of total solar energy, normal incidence
THICKNESS	5/32-inch nominal (.146-.166)
IRON CONTENT	.000%
DEFLECTION UNDER LOAD	
LIFE EXPECTANCY	Over 20 years
COST	34" x 96" = .93/ft^2 34-5/8" x 94-5/8" - 1.28/ft^2

GLAZING

MATERIAL Lustraglass Sheet

SOURCE ASG Industries
P.O. Box 929
Kingsport, Tennessee 37662
(615-245-0211)

TRANSMISSIVITY

Average of 2 values = 90.14 of total solar energy, normal incidence.

THICKNESS DS (.120-.130)

IRON CONTENT 0.07 - 0.08%

DEFLECTION UNDER LOAD	3.16"	34" x 96"	Free Edges)	Calculated
	0.70"	34" x 96"	Clamped Edges)	for 50 psf

LIFE EXPECTANCY > 20 years

COST

	34-5/8" x 94-5/8"	34" x 96"
Annealed	$.325/ft^2$	$.325/ft^2$
Tempered	Not Available	$.40/ft^2$

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GLAZING

MATERIAL	Lustra Crystal Sheet
SOURCE	ASG Industries P.O. Box 929 Kingsport, Tennessee 37662 (615-245-0211)

TRANSMISSIVITY

Average of 2 test values = 88.57% of total solar energy, normal incidence.

THICKNESS	3/16" (.186-.200)
IRON CONTENT	0.07 - 0.08%

DEFLECTION UNDER LOAD	.94"	34" x 96"	Free Edges)	Calculated for 50 psf
	.21"	34" x 96"	Clamped Edges)	

LIFE EXPECTANCY	> 20 years

COST

	34-5/8" x 94-5/8"	34" x 96"
Annealed	.4562 /ft^2	.4562 /ft^2
Tempered	.70 /ft^2	.56 /ft^2

GLAZING

MATERIAL	Tempered Glass - Herculite K
SOURCE	PPG Industries, Inc., 1 Gateway Center, Pittsburgh, Pennsylvania 15222, (412) 434-2824
TRANSMISSIVITY	83.3% of total solar energy, normal incidence
THICKNESS	3/16-inch
IRON CONTENT	
DEFLECTION UNDER LOAD	
LIFE EXPECTANCY	Over 20 years
COST	.43/ft.^{2} based on truckload shipments. Extra charge for larger than standard sizes.

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GLAZING

MATERIAL	Filon FRP Tedlar Finish on Weather Side, Supreme Grade
SOURCE.	Filon, 12333 S. Van Ness Avenue, Hawthorne, California 90250 (213) 757-5141
TRANSMISSIVITY	84.8% Total solar energy, normal incidence
THICKNESS	.030 (4 ounces) .037 (5 ounces)
IRON CONTENT	
DEFLECTION UNDER LOAD	
LIFE EXPECTANCY	20 years
COST	4 oz. $\$.325/ft^2$ 5 oz. $\$.36/ft^2$

Supreme Grade (without Tedlar but with a protective acrylic modified get coat) about 7¢ per ft^2 less.

GLAZING

MATERIAL	Fiberglass Reinforced Plastic - Kalwall Sunlite Premium
SOURCE	Kalwall Corporation, 1111 Candia Road, Manchester, New Hampshire 03103, (603) 627-3861
TRANSMISSIVITY	85-88% of total solar energy, normal incidence
THICKNESS	.025-inch, .040-inch
IRON CONTENT	
DEFLECTION UNDER LOAD	
LIFE EXPECTANCY	Approximately 20 years
COST	.025-inch - 29 cents/ft.^{2} .040-inch - 40 cents/ft.^{2}

GLAZING

MATERIAL	Polycarbonate - Lexan MR-4000
SOURCE	General Electric, Sheet Products Section, Plastics Business Division, 1 Plastics Avenue, Pittsfield, Massachusetts 01201
TRANSMISSIVITY	85% light transmission (1/8-inch thick sample)
THICKNESS	
IRON CONTENT	
DEFLECTION UNDER LOAD	
LIFE EXPECTANCY	
COST	4.06/ft^2 (1/8 inch)

GLAZING

MATERIAL	Tedlar Plastic Sheet
SOURCE	E.I. DuPont, Film Department, Wilmington, Delaware 19898
TRANSMISSIVITY	89% of solar energy, normal incidence
THICKNESS	4 mil
IRON CONTENT	
DEFLECTION UNDER LOAD	
LIFE EXPECTANCY	9 years
COST	15 cents/ft.^{2}

GLAZING

MATERIAL	LOF Glass
SOURCE	Libbey-Owens-Ford Company Technical Center 1701 East Broadway Toledo, Ohio 43605 (419-247-3731)

TRANSMISSIVITY

83% (float) 86% (sheet) Total solar energy, normal incidence.
Our tests show about 85%.

THICKNESS 1/8"

IRON CONTENT 0.15% (sheet glass) 0.12% (float glass)

DEFLECTION UNDER LOAD				
	3.16"	34" x 96"	Free Edges)	Calculated
	0.70"	34" x 96"	Clamped Edges)	for 50 psf

LIFE EXPECTANCY > 20 years

COST 35-40¢ (tempered)/ft.^{2}

APPENDIX B

TRANSMISSIVITY OF GLAZINGS

At the time of contract initiation, many materials were considered to be possible candidates as cover material for the solar collector. These included organic and inorganic materials. As more tests were conducted on these materials while cost analyses proceeded, it became clear that the leading candidates were glass because of a combination of three properties: strength, cost and transmissivity. A combination of the cost and transmissivity were used repeatedly in the Chamberlain analytical predictions computer program for determining the most cost-effective material. It became obvious that the Fourco Clearlite® and Cleartemp® glasses were the most cost-effective materials.

The tests conducted on the materials for determination of the transmissivity characteristics were as follows. A sight gage, with a total hemispherical pyranometer mounted in place, was fabricated as shown in Figure B-1. The complete unit was mounted on a tripod for ease in manipulation. The sight gage allowed solar alignment within ± 5° with ease. The inclinometer was included for measurements of transmissivity for incidence angles other than normal.

The tables on the following pages provided the results for determining the solar total transmittance.

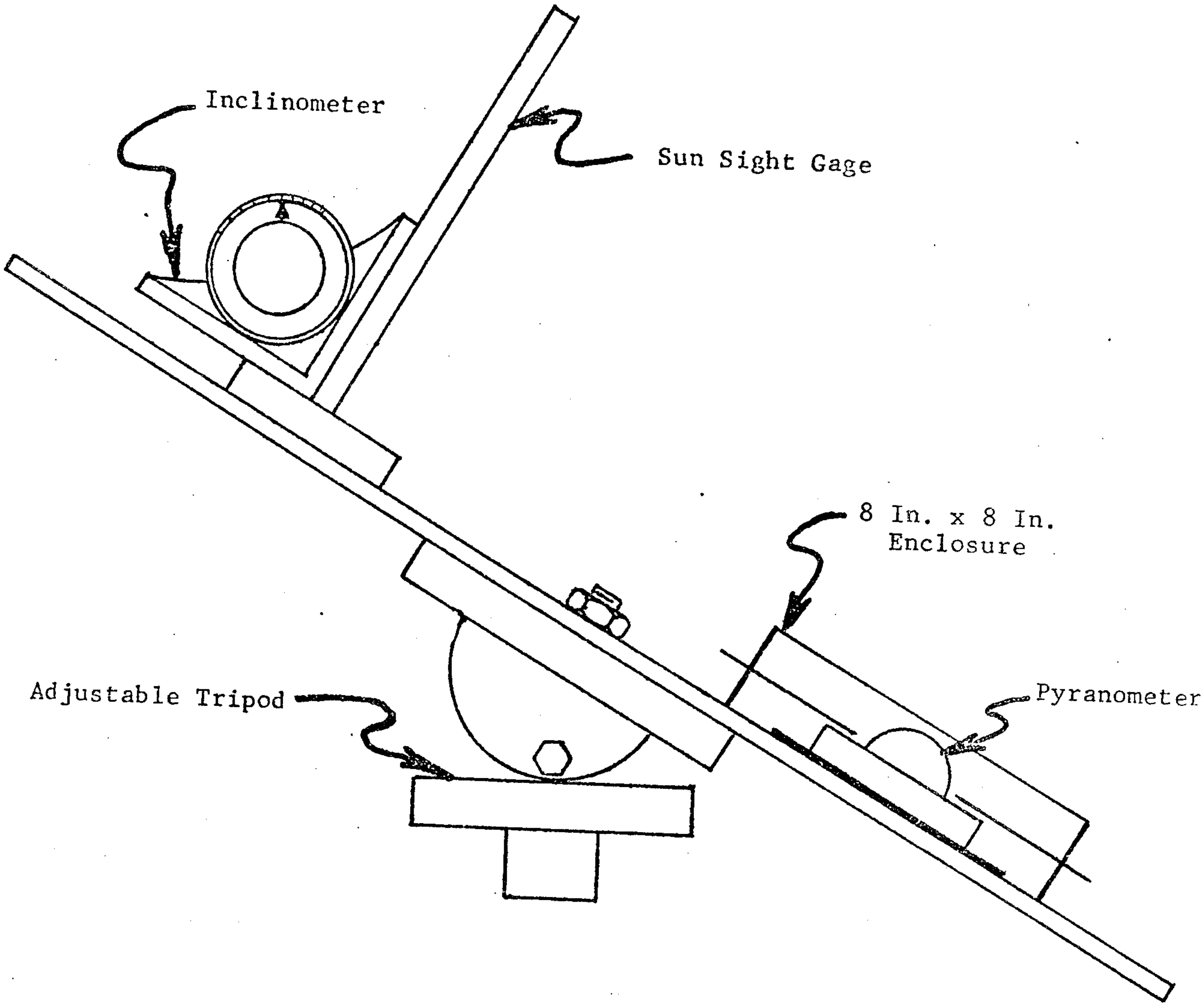

Figure B-1. Sight Gage for Alignment of Pyranometer During Transmissivity Tests

TABLE B-1. CANDIDATE COVER MATERIAL CHARACTERISTICS

DATE	TYPE OF MATERIAL	TRANSMITTANCE (%)	IRON CONTENT (%)	THICKNESS (in.)	WEIGHT (lb/ft^2)	COEF. THERMAL EXPANSION x 10^6 (in./in./°F)	MAXIMUM TEMPERATURE (°F)
	FOURCO GLASS COMPANY						
16 May 75	Clearlite (Harding) No. 1	87.51	0.059	3/16	2.5	6.5	-
16 May 75	Clearlite (Harding) No. 2	87.80	0.059	3/16	2.5	6.5	-
16 May 75	Clearlite (Harding) No. 1	89.60	0.059	1/8	1.65	6.5	-
16 May 75	Clearlite (Harding) No. 2	90.00	0.059	1/8	1.65	6.5	-
19 May 75	Clearlite (Harding)	88.53	0.095	1/8	1.65	6.5	-
19 May 75	Clearlite (Harding)	86.24	0.093	3/16	2.5	6.5	-
19 May 75	Clearlite (Adamston)	89.75	0.061	1/8	1.65	6.5	-
19 May 75	Clearlite (Adamston)	88.07	0.066	1/8	1.65	6.5	-
23 May 75	Clearlite (Harding) No. 1	89.86	0.059	1/8	1.65	6.5	-
23 May 75	Clearlite (Harding) No. 2	90.21	0.059	1/8	1.65	6.5	-
23 May 75	Clearlite (Harding) No. 1	87.87	0.059	3/16	2.5	6.5	-
23 May 75	Clearlite (Harding) No. 2	87.93	0.059	3/16	2.5	6.5	-
2 Jun 75	Clearlite (Harding) at Angles of Incidence Other Than Normal						
	1/8-Inch 0°	90.03	0.059	1/8	1.65	6.5	-
	10°	89.75					
	20°	88.00					
	30°	83.47					
	40°	74.42					
	50°	63.62					
2 Jun 75	Clearlite (Harding) at Angles of Incidence Other Than Normal						
	3/16-Inch 0°	88.22	0.059	3/16	2.5	6.5	-
	10°	88.13					
	20°	85.75					
	30°	79.00					
	40°	68.49					
	50°	57.26					
7 Jul 75	Clearlite (Harding)	88.23	0.059	3/16	2.5	6.5	-
10 Jul 75	Clearlite (Harding)	90.26	0.059	1/8	1.65	6.5	-
15 Jul 75	Clearlite (Harding)	90.26	0.059	1/8	1.65	6.5	-
18 Jul 75	Clearlite (Harding)	88.50	0.059	3/16	2.5	6.5	-
24 Jul 75	Clearlite (Harding)	90.29	0.059	1/8	1.65	6.5	-
24 Jul 75	Clearlite (Harding)	88.40	0.059	3/16	2.5	6.5	-
1 Aug 75	Clearlite (Harding)	89.99	0.059	1/8	1.65	6.5	-
1 Aug 75	Clearlite (Harding)	88.23	0.059	3/16	2.5	6.5	-
22 Aug 75	Clearlite (Harding)	90.22	0.059	1/8	1.65	6.5	-
22 Aug 75	Clearlite (Harding)	87.74	0.059	3/16	2.5	6.5	-
25 Aug 75	Clearlite (Rolland)	86.15	0.094	1/8	1.65	6.5	-
25 Aug 75	Clearlite (Rolland)	81.54	0.098	3/16	2.5	6.5	-
29 Aug 75	Clearlite (Harding)	89.46	0.059	1/8	1.65	6.5	-
29 Aug 75	Clearlite (Harding)	87.93	0.059	3/16	2.5	6.5	-
7 Sep 75	Clearlite (Harding)	89.81	0.059	1/8	1.65	6.5	-
7 Sep 75	Clearlite (Harding)	87.86	0.059	3/16	2.5	6.5	-
12 Sep 75	Clearlite (Harding)	89.73	0.059	1/8	1.65	6.5	-
12 Sep 75	Clearlite (Harding)	88.31	0.059	3/16	2.5	6.5	-

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TABLE B-1 (CONTINUED)

DATE	TYPE OF MATERIAL	TRANSMITTANCE (%)	IRON CONTENT (%)	THICKNESS (in.)	WEIGHT (lb/ft^2)	COEF. THERMAL EXPANSION $\times 10^6$ (in./in./°F)	MAXIMUM TEMPERATURE (°F)
			ASG INDUSTRIES				
1 May 75	Crystal 76 Water White	91.83	0.0	3/16	2.5	6.5	-
1 May 75	Crystal 76 Water White	92.41	0.0	5/32	2.1	6.5	-
5 Jun 75	Crystal 76 Water White (No. 1)	93.59	0.0	5/32	2.1	6.5	-
5 Jun 75	Crystal 76 Water White (No. 2)	92.40	0.0	5/32	2.1	6.5	-
5 Jun 75	Crystal 76 Water White (No. 3)	92.22	0.0	5/32	2.1	6.5	-
5 Jun 75	Crystal 76 Water White (No. 4)	92.93	0.0	5/32	2.1	6.5	-
5 Jun 75	Crystal 76 Water White (Double Glazing)	84.59	0.0	2 (5/32)	4.2	6.5	-
			PITTSBURGH PLATE GLASS				
1 May 75	Herculite K	83.3	Unknown	3/16	2.5	6.5	-
			LIBBY-OWENS-FORD GLASS				
1 May 75	Annealed/Annealed (Double Glazing)	71.68	Unknown	2 (1/8)	3.3	6.5	-
1 May 75	Tempered/Tempered (Double Glazing)	72.02	Unknown	2 (1/8)	3.3	6.5	-
1 May 75	Tempered/Tin Oxide Coated (Double Glazing)	60.02	Unknown	2 (1/8)	3.3	6.5	-
1 May 75	Tin Oxide Coated With Overwash Removed	81.77	Unknown	1/8	1.65	6.5	-
1 May 75	Tin Oxide Coated and Overwash	70.25	Unknown	1/8	1.65	6.5	-
			FILON CORPORATION				
1 May 75	Filon Sheet	85.81	N/A	0.030	0.25	18-22	200
1 May 75	Filon Sheet	85.27	N/A	0.037	0.31	18-22	200
			KALWALL CORPORATION				
1 May 75	Sunlite Premium	90.26	N/A	0.025	0.25	20	200
1 May 75	Sunlite Premium	85.71	N/A	0.040	0.40	20	200
1 May 75	Sunlite Regular	92.20	N/A	0.025	0.25	20	200
1 May 75	Sunlite Regular	87.56	N/A	0.040	0.40	20	200
			GENERAL ELECTRIC PLASTICS DIVISION				
1 May 75	MR-4000	85.5	N/A	1/8	0.78	37.5	Unknown
			E. I. DUPONT DE NEMOURS AND COMPANY				
1 May 75	Tedlar Sheet	89.19	N/A	0.004	-	24	200
1 May 75	Tedlar/Annealed Glass (Double Glazing)	79.86	N/A	1/8-Glass .004-Tedlar	1.65	Glass 6.5 Tedlar 24	200
1 May 75	Mylar	85.0	N/A	0.014	-	15	Unknown

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APPENDIX C

DEFLECTION OF GLASS UNDER UNIFORM STATIC LOADS

The glazing of the solar collector will be subjected to environmental loads in much the same manner as a patio cover. Code requirements will be established which will make it mandatory to meet certain specified wind and snow loads. Further, Chamberlain must have a high confidence that breakage due to the wind and/or snow loads will not occur regardless of whether code restrictions are currently on the books in localities where the collector may be installed.

The design of the solar collector requires a glass size of approximately 36-inches by 96-inches. The cost effectiveness study has shown (see Section 4) that the Fourco Clearlite® and Cleartemp® glasses are the primary candidates for use in the collector. Thus the selection of the glazings must be made from either 1/8- or 3/16-inch thick Clearlite® (annealed) or Cleartemp® (tempered). For collector applications, thermal, strength and safety code requirements will necessitate that tempered glass be used. For a double-glazed unit, the inner glazing as well as the outside cover must be tempered.

Tests were performed for determination of the deflection characteristics of both 1/8- and 3/16-inch thick glasses in tempered and annealed conditions. The tests were performed using a uniform static load. The load limit was approximately 50 psf or until breakage occurred. Since these results would be applicable to both the NASA/MSFC collector design, which uses no metal framework as an integral part of the cover assembly and the Chamberlain commercial collector, which uses an extruded aluminum cover frame, the tests were conducted with and without the aluminum frame.

The experimental test bed is shown schematically in Figure C-1. The base 2 inch by 4 inch box allows the glass (with or without the aluminum frame) to be supported uniformly along the edges. The glass assembly (with or without the metal frame) is placed on the lower assembly. On top of this

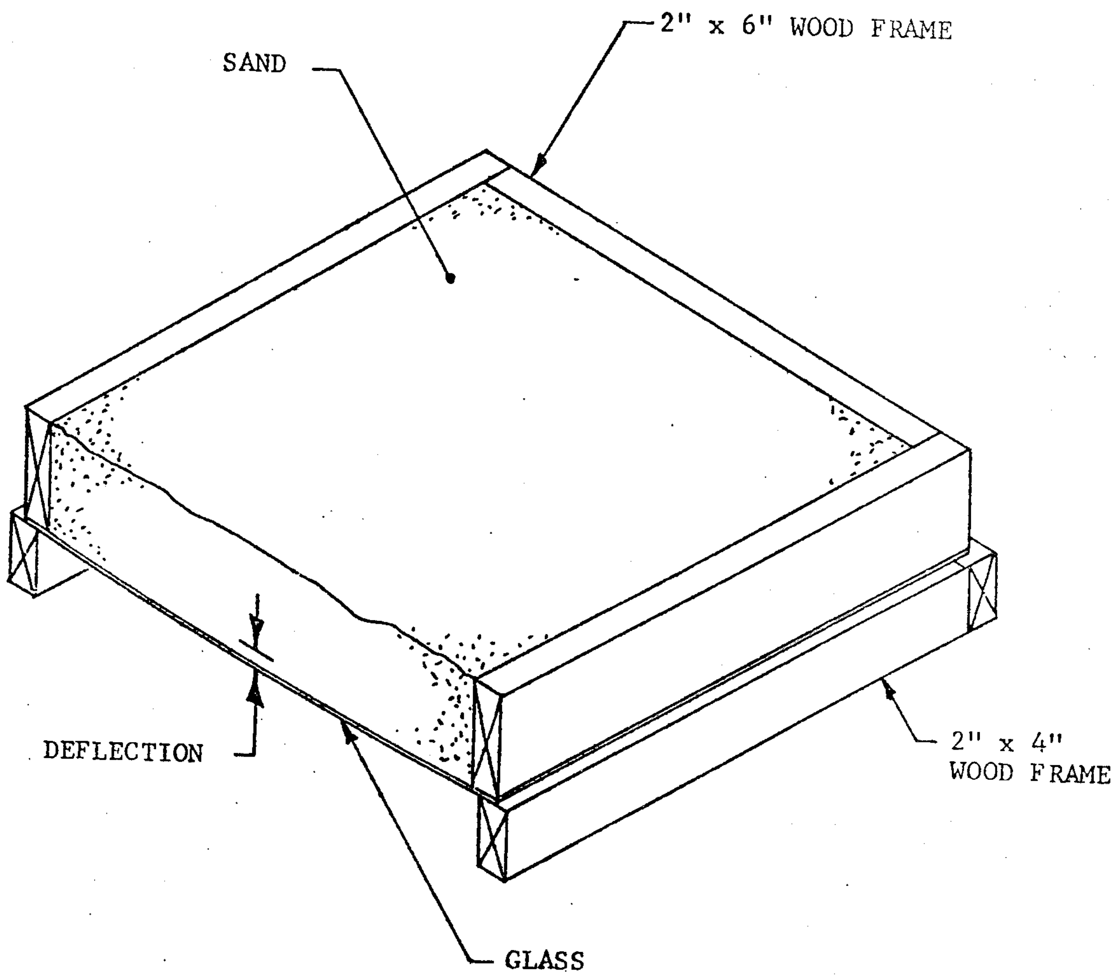

Figure C-1. Sketch of Test Setup for Deflection Tests of Glass Under Uniform Static Load

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assembly is placed a framework similar to the lower one, but constructed of 2 inch by 6 inch wood. A 6 inch depth is necessary to retain the loading material (sand) when sufficient volume is used to apply a 50 psf uniform load. A dial indicator is mounted on a beam across the center of the fixture, making contact with the geometric center of the glass. All measurements taken were from this single, maximum deflection point. During the test procedure the load was applied as uniformly as possible, with attempts being made to "contour" the upper surface of the sand to conform to the center-point deflection. The sand was loaded in uniform increments of 1/2 or 1.0 inch as nearly as possible. The 1/2 inch increments were used for the annealed glass because of the uncertainty of whether breakage would occur. Deflections were measured at each load increment. The test results are shown in Tables C-1 and C-2.

The results indicate that the load carrying capability of the tempered glass is an acceptable value. The ability of the annealed glass to withstand a static load is not as high as the tempered and would not meet requirements now being specified in Federal procurements (combined wind/snow loads of 38 psf in the normal direction). Although deflections of the 1/8 inch tempered glass is excessive, it does meet the loading requirements. The deflections are such that the absorber plate would provide an additional load-carrying capability when the deflection is sufficient (in the one-cover design) to allow contact between the two pieces to occur.

Two phenomena occurred which were not expected. First, the specimen which was tested with the metal frame (as in the Chamberlain commercial collector) demonstrated deflections larger than the specimen tested without a frame (as in the NASA/MSFC collector). The reason for this occurrence is not obvious, but one explanation would be that the relatively soft glazing channel used between the glass and metal frame provided less edge restraint than when the bare glass was "pinched" between the two wooden frames. This edge effect would be very minimal, and it is not clear that this was actually what promoted this occurrence.

TABLE C-1. TABULATED RESULTS OF DEFLECTION OF GLASS WITH FRAME UNDER UNIFORM STATIC LOAD

	Annealed				Tempered			
	1/8-Inch		3/16-Inch		1/8-Inch		3/16-Inch	
SAND DEPTH (inches)	DEFLECTION (inches)	LOAD (psf)	DEFLECTION (inches)	LOAD (psf)	DEFLECTION (inches)	LOAD (psf)	DEFLECTION (inches)	LOAD (psf)
0.0	0.100	0.0	0.020	0.0	0.180	0.0	0.070	0.0
1.0	0.518	8.0	0.184	8.0	0.752	8.5	0.328	8.5
2.0	0.795	16.0	0.328	16.0	0.981	17.0	0.495	17.0
2.5	-	-	-	-	-	-	-	-
3.0	0.968	24.0	0.460	24.0	1.160	25.5	0.621	25.5
3.5	-	-	-	-	-	-	-	-
4.0	1.118	32.0	0.570	32.0	1.313	34.0	0.742	34.0
5.0	Broken	-	0.655	40.0	1.445	42.5	0.845	42.5
6.0	-	-	0.730	48.0	1.551	51.0	0.928	51.0
6.25	-	-	0.752	50.0	-	-	-	-

TABLE C-2. TABULATED RESULTS OF DEFLECTION OF GLASS WITHOUT FRAME UNDER UNIFORM STATIC LOAD

	Annealed				Tempered			
	1/8-Inch		3/16-Inch		1/8-Inch		3/16-Inch	
SAND DEPTH (inches)	DEFLECTION (inches)	LOAD (psf)	DEFLECTION (inches)	LOAD (psf)	DEFLECTION (inches)	LOAD (psf)	DEFLECTION (inches)	LOAD (psf)
0.0	0.100	0.0	0.020	0.0	0.200	0.0	0.070	0.0
1.0	0.470	7.25	0.125	6.75	0.693	8.5	0.302	8.5
2.0	0.715	14.5	0.252	14.0	0.978	17.0	0.465	17.0
2.5	0.825	18.1	-	-	-	-	-	-
3.0	0.897	21.8	0.380	21.3	1.153	25.5	0.602	25.5
3.5	0.982	25.4	-	-	-	-	-	-
4.0	1.060	29.0	0.482	28.5	1.313	34.0	0.723	34.0
5.0	Broken		0.593	35.8	1.428	42.5	0.812	42.5
6.0	-	-	Broken		1.538	51.0	0.883	51.0

The second phenomena was the breakage tendencies of the annealed glass. During the loading process, time was expended in contouring the sand, loading it slowly in order to prevent a dynamic loading situation, and recording the data. Several times, breakage occurred after large elapsed times, of the order of 1/2-hour following the loading completion. E. K. Pavelchek and R. H. Doremus ("Static Fatigue in Glass - A Reappraisal," Rensselaer Polytechnic Institute, Troy, New York) indicate that static fatigue may cause failure if the glass is loaded above a certain stress level for a period of time.

APPENDIX D

ABSORBER PLATES

ABSORBER PLATES

TYPE

Stitch welded, pressure expanded, 20 gauge mild steel

SOURCE

Turbo Refrigerating Company
P.O. Box 396
Denton, Texas 76201 (817-387-4301)
Attention: Bill Hagen

PRESSURE RATINGS (psi)

OPERATING	50 psig
TEST	Proof test and leak test at 75 psig
BURST	150 psig

PRESSURE DROP THROUGH PANEL AT 0.5 GPH/FT.^{2} FLOW RATE (WATER)

CONNECTIONS: As required

FLOW PASSAGES: 0.060 inch nominal flow passage height over uniform portions of panel at short welds

MANIFOLDS: 1/4 - 1/2 inch manifold height across width of panel to first row of spot welds

STITCH PATTERN: In line both ways or 50% offset row to row

ABSORBER PLATES

TYPE

Stitch welded, pressure expanded, 20 gauge mild steel

SOURCE

Tranter, Incorporated
735 East Hazel Street
Lansing, Michigan 48909 (517-372-8410)
Attention: Bob Rowland

PRESSURE RATINGS (psi)

OPERATING	50 psig
TEST	Proof test and leak test at 75 psig
BURST	150 psig

PRESSURE DROP THROUGH PANEL AT 0.5 GPH/FT.^{2} FLOW RATE (WATER)

CONNECTIONS: As required

FLOW PASSAGES: 0.060 inch nominal flow passage height over uniform portions of panel at short welds

MANIFOLDS: 1/4 - 1/2 inch manifold height across width of panel to first row of spot welds

STITCH PATTERN: In line both ways or 50% offset row to row

ABSORBER PLATES

TYPE

Stitch welded, pressure expanded, 20 gauge mild steel

SOURCE

Paul Mueller Company
P.O. Box 828
Springfield, Missouri 65801 (417-865-2831)
Attention: Dave Harvey

PRESSURE RATINGS (psi)

OPERATING	50 psig
TEST	Proof test and leak test at 75 psig
BURST	150 psig

PRESSURE DROP THROUGH PANEL AT 0.5 GPH/FT.^{2} FLOW RATE (WATER)

CONNECTIONS: As required

FLOW PASSAGES: 0.060 inch nominal flow passage height over uniform portion of panel at short welds

MANIFOLDS: 1/4 - 1/2 inch manifold height across width of panel to first row of spot welds

STITCH PATTERN: In line both ways or 50% offset row to row

APPENDIX E

ABSORBER COATINGS

ABSORBER COATINGS

MATERIAL	Paint Caldwell C-1077-3
SOURCE	Caldwell Chemical Coatings Corporation, 209 Ardmore Road, Fayetteville, Tennessee 37334, (615) 433-1571
SURFACE PREPARATION	Degrease absorber plate.
METHOD OF APPLICATION	Spray black paint on front of absorber. Spray back with aluminum paint. Bake at 350°F for 15 minutes.
ABSORPTIVITY	(solar) .90
EMISSIVITY	(IR) .58
THICKNESS	0.9-1.0 mil, ± 0.1 mil
COLOR	Black
MAXIMUM TEMPERATURE	Gets soft at 400 but does not run.
COST	Approximately 4.50-5.00/gallon

ABSORBER COATINGS

MATERIAL	Black Paint, Caldwell 129-386
SOURCE	Caldwell Chemical Coatings Corporation, 209 Ardmore Road, Fayetteville, Tennessee 37334, (615) 433-1571
SURFACE PREPARATION	Degrease absorber plate.
METHOD OF APPLICATION	Spray black paint onto front of absorber plate. Spray back with aluminum paint. Bake at 350°F for 15 minutes.
ABSORPTIVITY	(solar) .94-.95
EMISSIVITY	(IR) .87-.88
THICKNESS	No recommended thickness.
COLOR	Black
MAXIMUM TEMPERATURE	900°
COST	6.50/gallon

ABSORBER COATINGS

MATERIAL	Caldwell Paint 1595-3
SOURCE	Caldwell Chemical Coatings Corporation, 209 Ardmore Road, Fayetteville, Tennessee 37334, (615) 433-1571
SURFACE PREPARATION	Degrease absorber plate.
METHOD OF APPLICATION	Spray black paint onto front of absorber plate. Spray back with aluminum paint. Bake at 350°F for 15 minutes.
ABSORPTIVITY	(solar) .92-.93
EMISSIVITY	(IR) .83
THICKNESS	No recommended thickness.
COLOR	Black
MAXIMUM TEMPERATURE	900
COST	Approximately 7.00/gallon

ABSORBER COATINGS

MATERIAL	3M Nextel Paint	101-C10 901-P1	Paint Dark Primer
SOURCE	3M Company, P.O. Box 327, Nevada, Missouri 64772		

SURFACE PREPARATION

1. Degrease (Tricloroethylene).
2. Dip in Bonderite (phosphate) 3-5 minutes.
3. Dip in Parcolene (chromate) 10 seconds.

METHOD OF APPLICATION

1. Spray entire surface with primer and air dry.
2. Spray entire surface with Nextel.
3. Bake at 250° for 30 minutes.

ABSORPTIVITY	(solar) .95
EMISSIVITY	(IR) .95
THICKNESS	Primer 1/2 mil, Paint 2-1/2 mils
COLOR	Black
MAXIMUM TEMPERATURE	300°F
COST	Paint 34.00/gallon Primer 9.50/gallon

ABSORBER COATINGS

MATERIAL — Black Copper Over Copper (on Steel)

SOURCE — Enthone, Inc., Solar Systems Division, P.O. Box 1900, New Haven, Connecticut 06508, (203) 934-8611, Attention: Mr. Francis A. Schneiders, Executive Vice President

SURFACE PREPARATION (Several sequences are possible. The following is suitable for high production sheet steel) - Rinse after each step.

1. Emulsion soak
2. Electrolytic alkaline
3. Hydrochloric acid

(At this point the steel should be free of grease, dirt and oxides, and be ready for electroplating)

METHOD OF APPLICATION

1. Copper plate (minimum of 0.0002 inch)
2. Rinse
3. A proprietary chemical treatment to form a thin layer of black copper (copper oxide). This involves four separate chemical dip treatments with intermediate rinses.

ABSORPTIVITY — $\alpha_{solar} = 0.90$

EMISSIVITY — $\epsilon_{IR} = 0.12$

THICKNESS

COLOR — Black

MAXIMUM TEMPERATURE — 375°F

COST — ~ $0.60/square foot. No rack charge on 3' x 8' plates.

ABSORBER COATINGS

MATERIAL: Black Chrome over Nickel (on steel)

SOURCE: Olympic Plating Industries
208 15th Street, S.W.
Canton, Ohio 44707 (206-452-8856)

Attention: Mr. Richard Brady
Vice President, Sales

SURFACE PREPARATION: (Several treatments are possible. The following is suitable for high production of sheet metal.) Rinse after each step.

1. Emulsion soak
2. Electrolytic alkaline
3. Hydrochloric acid

At this point the steel should be free of grease, dirt and oxides and be ready for electroplating.

METHOD OF APPLICATION: Rinse after each step.

1. Nickel Plate - semi-bright 0.001 - 0.002 inch
2. Black Chromium Plate - thickness such that $\alpha = .90$, $\epsilon = .10$ or $\alpha = .95$, $\epsilon = .17$

Typically about one minute in plating solution.

ABSORPTIVITY: (Solar) .90 or .95

EMISSIVITY: (IR) = 0.10 or .17

THICKNESS: As above

COLOR: Black

MAXIMUM TEMPERATURE: > 500°F

COST: ∿ $1.29 - $1.65/ft.^{2} plus $1,200.00 rack charge (for 3' x 8')

COMMENT: .95/.17 is best for most applications.

APPENDIX F

EFFECT OF CHANGES IN ABSORPTIVITY AND EMISSIVITY ON COLLECTOR PERFORMANCE

Olympic Plating, Canton, Ohio, provided Chamberlain with the information that the black chrome selective coating in two different values of absorptivity and emissivity could be furnished. These values were 0.90/0.10 and 0.95/0.17. This brought up the questions:

(1) Does the gain in α outweigh the gain in ϵ?

(2) If so, does this hold at all temperatures and insolations?

Answers were found to the questions by a computer analysis and by applying a method of comparison reported by H. Tabor, et al in paper S/46 of the 1961 U. N. Conference on New Sources of Energy (Vol. 4, p. 618).

Computer runs were made with both coatings at four different temperatures and three different insolations. The collector was a 2 ft. by 6 ft. model with one Fourco(R) glass cover. The results are shown below:

	INSOLATION BTU/HR.-FT.^{2}			
	150	250	350	COATING
INLET TEMPERATURE		EFFICIENCY		α AND ϵ VALUES
90	67.8	67.6	67.3	
130	52.5	58.2	60.5	0.95/0.17
170	28.3	43.6	49.9	
210	8.8	31.8	41.5	
90	64.9	64.8	64.5	
130	51.0	56.2	58.2	0.90/0.10
170	28.8	42.8	48.6	
210	11.1	32.1	41.0	

The three underlined efficiencies are the only ones in which the 0.90/0.10 coating outperforms the 0.95/0.17. The reduced losses from the low emissivity of the 0.90/0.10 are not as important as the increased solar gains from the higher absorptivity of the 0.95/0.17 at the higher temperatures. Note that the gains vary not only with temperature, but also with insolation. It becomes apparent that at some point the increase in absorptivity does not outweigh the accompanying increase in emissivity. An approximation to this point was derived by Tabor.

Work accomplished by Tabor resulted in the following equation:

$$d\,\alpha > \frac{\sigma\,(T^4 - T_o{}^4)}{P\,\overline{Q}}\,d\,\epsilon$$

where:

P = concentration ratio (area of collector aperture to area of heated surface = 1 for flat plate)

T = average temperature of the heated surface in degrees absolute

T_o = ambient temperature in degrees absolute

α = absorptivity of the heated surface

ϵ = emissivity of the heated surface

$\overline{Q}$ = average insolation per unit area

σ = Stefan-Boltzman constant (0.1714 x 10^{-8} BTU/hr.-ft.^{2}-°R)

The efficiency is only increased when the equation is true; i.e., when the increase in absorptivity is greater than a constant times the emissivity. As an example: at T_o = 90°F (550°R), T = 174°F (634°R), $\overline{Q}$ = 150 BTU/hr.-ft.^{2}, is there an advantage in using the 0.95/0.17 coating rather than the 0.90/0.10 coating?

$$d\,\epsilon > \frac{\sigma\,(T^4 - T_o{}^4)}{P\,\overline{Q}}\,d\,\epsilon$$

$$.05 > \frac{.1714 \times 10^{-8}\,(634^4 - 550^4)}{1.150}\,(.07)$$

$$.05 > .80\,(.07)$$

$$.05 \not> .056$$

Therefore the 0.95/0.17 coating is not more efficient. This corresponds to the result given by the computer analysis (28.3% versus 28.8%).

A plot was made for the values used in the computer analysis (Reference Figure F-1 on the following page). The dashed line indicates the region where the change makes no difference; i.e., where

$$.05 = \frac{\sigma\ (T^4 - T_o{}^4)}{P\ \bar{Q}}\ .07.$$

Notice the plot shows three points where it is advantageous to use the 0.90/0.10 coating. These points correspond to those indicated by the computer analysis.

In an effort to easily evaluate on an efficiency basis the effect of changes in α and ϵ, the accompanying graphs (Figures F-2 and F-3) were made.

The graph can be used in two ways: first, to determine the $\frac{\sigma\ (T^4 - T_o{}^4)}{P\ \bar{Q}}$ value to evaluate the inequality; second, the value $d\ \alpha / d\ \epsilon$ can be determined and a line drawn at that value of $\frac{\sigma\ (T^4 - T_o{}^4)}{P\ \bar{Q}}$. All conditions corresponding to the points below the line will be those which favor the higher absorptance coating.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

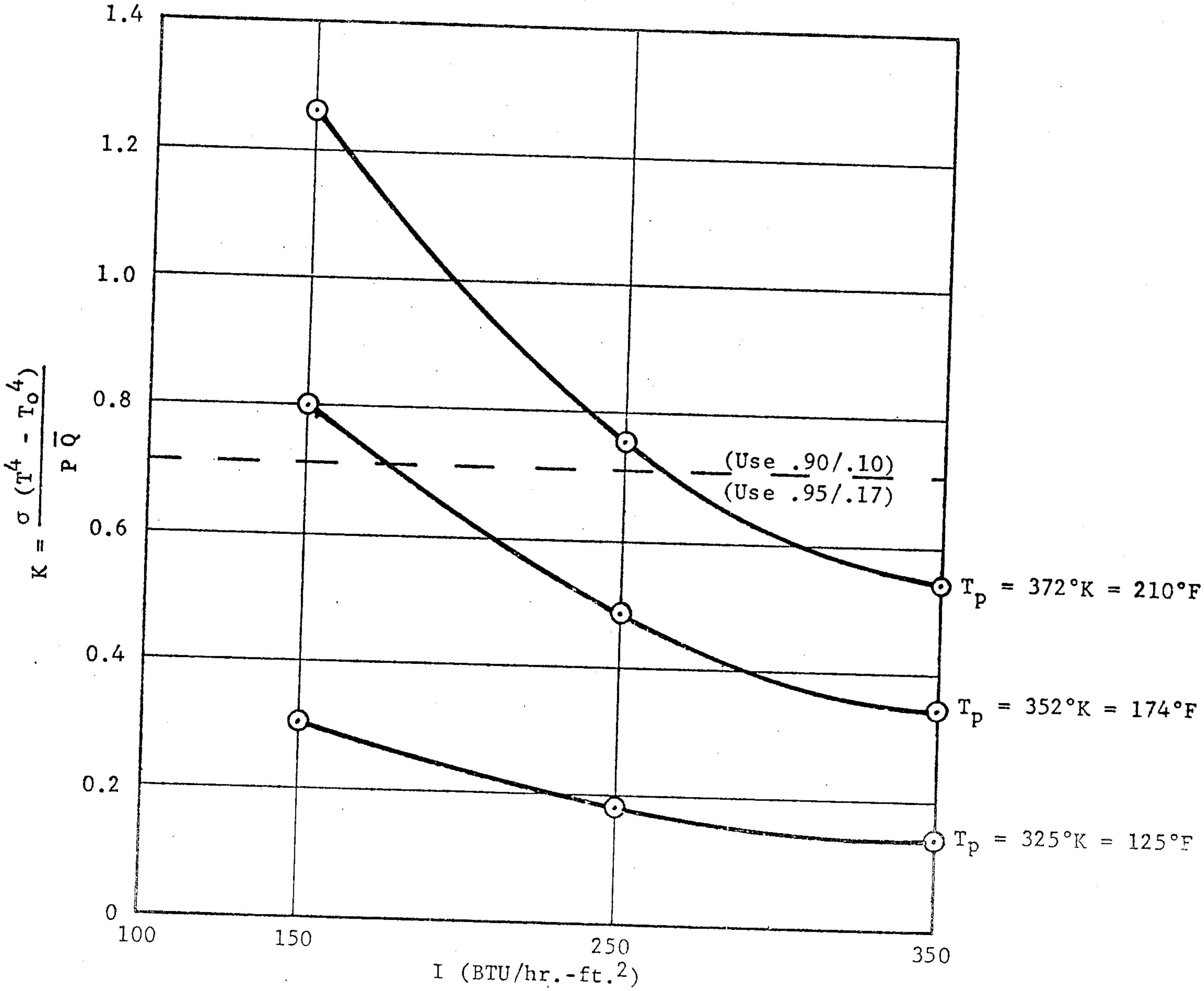
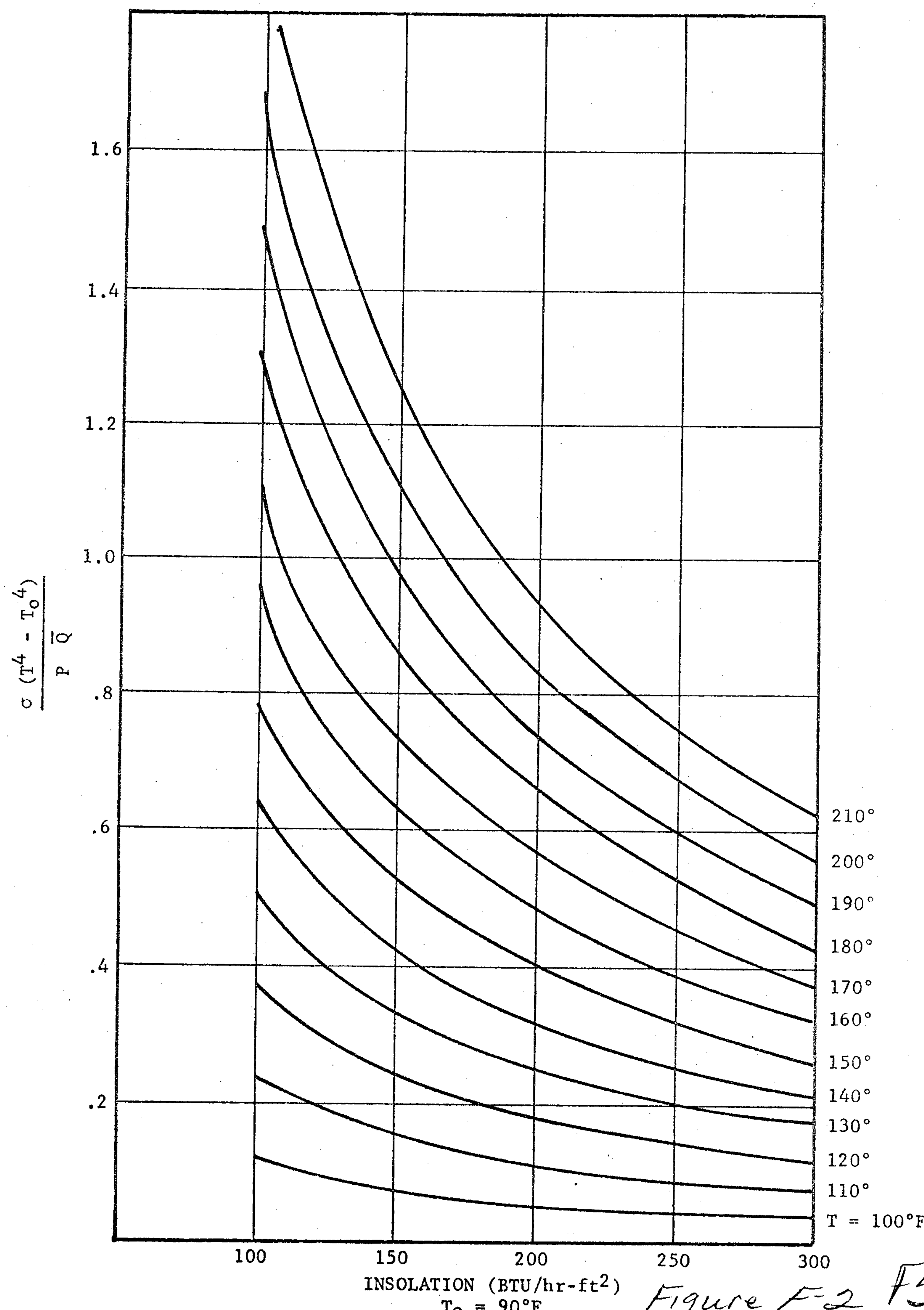
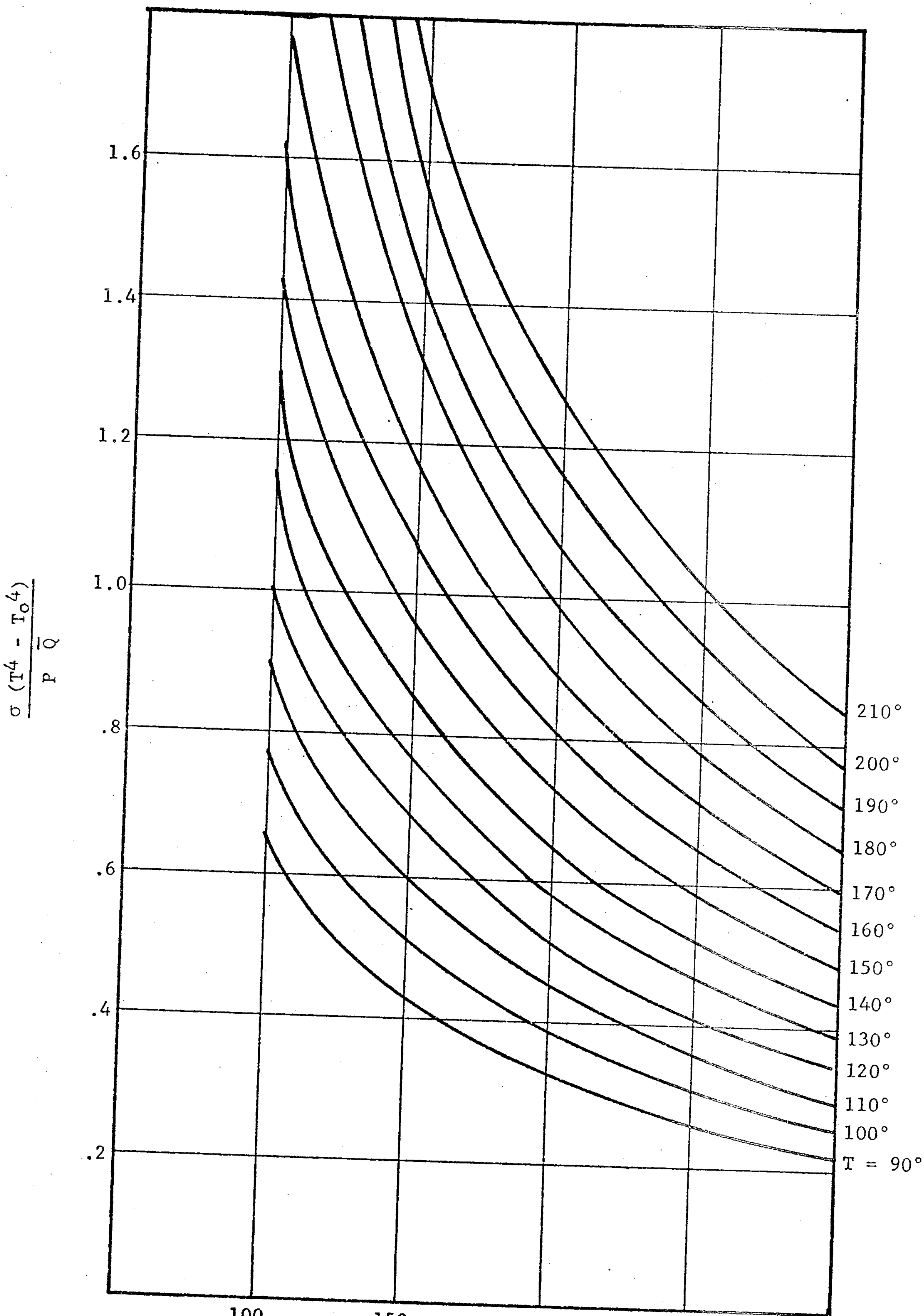


Figure F-1. Result of Analyses to Determine Effect of α and ϵ Values Available with Black Chrome



1.6
1.4
1.2
1.0
.8
.6
.4
.2
$\frac{\sigma (T^4 - T_o^4)}{P \overline{Q}}$
100
150
200
250
300
INSOLATION (BTU/hr-ft^2)
T_o = 90°F
210°
200°
190°
180°
170°
160°
150°
140°
130°
120°
110°
T = 100°F

Figure F-2 F5



INSOLATION (BTU/hr-ft^2)
T_o = 20°F

Figure F-3
F-6

APPENDIX G

INSULATIONS

G-ii

FOAM

TYPE	Autofroth(R) Urethane	"A" Component	X-7345A
		"B" Component	108-X-7405

SOURCE Olin Chemicals Specialty Urethanes, 120 Long Ridge Road, Stamford, Connecticut 06904

DENSITY (Lb./Ft.^{3}) 2.0

RATED MAXIMUM TEMPERATURE (°F) 210

TENSILE STRENGTH 35-44 psi

BLOWING AGENT Fluorocarbon

AGING CHARACTERISTICS 158° 28 Days 4-13% Volume Change

K (BTU-In./Hr.-Sq. Ft.-°F) .146 at 20-75°

OUTGASSING TEMPERATURE 220

FIRE RATING: FLAME SPREAD 25

FUEL CONTRIBUTED Not Available

SMOKE DEVELOPED 470

COST	PER POUND	PER SQUARE FOOT COLLECTOR (R = 10 at 75°)
100	.85	
1,000		
10,000		
50,000		

COMMENT: Outgasses at low temperature, smoke developed too high.

FOAM

TYPE UFC-160 Trimer Urethane

SOURCE United Foam Corporation, 19201 S. Reyes Avenue, Compton, California 90221, (213) 774-5600

DENSITY (Lb./Ft.^{3}) Nominal 2.0

RATED MAXIMUM TEMPERATURE (°F) 300

TENSILE STRENGTH 68 psi

BLOWING AGENT Fluorocarbon

AGING CHARACTERISTICS 7 Days 300°F 2.5% Volume Change

K (BTU-In./Hr.-Sq. Ft.-°F) .13 at 70°

OUTGASSING TEMPERATURE

FIRE RATING: FLAME SPREAD)
FUEL CONTRIBUTED) Has not been tested by UL. Contains fire retardants and UFC believes that it will meet the codes if tested.
SMOKE DEVELOPED)

COST	PER POUND	PER SQUARE FOOT COLLECTOR (R = 10 at 75°)
100	~ .74	
1,000		
10,000		
50,000		

COMMENT: See fire rating.

FOAM

TYPE	UFC-175 Isocyanurate
SOURCE	United Foam Corporation, 19201 S. Reyes Avenue, Compton, California 90221, (213) 774-5600
DENSITY (Lb./Ft.^{3})	Nominal 2.6
RATED MAXIMUM TEMPERATURE (°F)	400
TENSILE STRENGTH	75 psi
BLOWING AGENT	Fluorocarbon
AGING CHARACTERISTICS	7 Days 300°F 2.5% Volume Change 7 Days 400°F 5% Volume Change
K (BTU-In./Hr.-Sq. Ft.-°F)	.13 at 70°
OUTGASSING TEMPERATURE	

FIRE RATING:	FLAME SPREAD	25	2" Sample
	FUEL CONTRIBUTED	15	
	SMOKE DEVELOPED	200	

COST	PER POUND	PER SQUARE FOOT COLLECTOR (R = 10 at 75°)
100	~ .70	
1,000		
10,000		
50,000		

COMMENT: The only one known which has high temperature capabilities and a UL rating. It is a little cheaper than UFC 160 and is rated 100° higher.

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

FOAM

TYPE CPR 421 Isocyanurate

SOURCE Upjohn CPR Division, 555 Alaska Avenue,
Torrance, California 90503, (213) 320-3550

DENSITY (Lb./Ft.^{3}) Nominal 2.0

RATED MAXIMUM TEMPERATURE (°F) 375 with Char

TENSILE STRENGTH Parallel 40 psi

BLOWING AGENT Fluorocarbon

AGING CHARACTERISTICS 7 Days 300°F -4% Volume Change
28 Days 300°F -12% Volume Change

K (BTU-In./Hr.-Sq. Ft.-°F) .15 at 70-75°

OUTGASSING TEMPERATURE

		1" Thick	1-1/2 to 4" Thick
FIRE RATING:	FLAME SPREAD	25	25
	FUEL CONTRIBUTED	20	15
	SMOKE DEVELOPED	300	Over 500

COST	PER POUND	PER SQUARE FOOT COLLECTOR (R = 10 at 75°)
100		
1,000		
10,000		
50,000		

COMMENT: This product is no longer being produced.

FOAM

TYPE Rubifroth Isocyanurate - Typical Values

SOURCE Uniroyal, Rubicon Chemicals, Elm Street, Naugatuck, Connecticut 06770, (203) 723-3749

DENSITY (Lb./Ft.^{3}) Nominal 2.0

RATED MAXIMUM TEMPERATURE (°F) 300

TENSILE STRENGTH Approximately 40 psi

BLOWING AGENT Fluorocarbon

AGING CHARACTERISTICS 7 Days at 250°, 2% Volume Change

K (BTU-In./Hr.-Sq. Ft.-°F) .16 at 70-75

OUTGASSING TEMPERATURE 220

FIRE RATING: FLAME SPREAD 25

FUEL CONTRIBUTED Not Available

SMOKE DEVELOPED 200-300

COST	PER POUND	PER SQUARE FOOT COLLECTOR (R = 10 at 75°)
100		
1,000		
10,000		
50,000		

COMMENT: Rather than a specific foam, this is really a process used for panels.

REPRODUCIBILITY OF THE

FOAM

TYPE 520-2 Urethane

SOURCE API Systems, 11034 Sutter Avenue,
Pacoima, California 91331, (213) 899-2583

DENSITY (Lb./Ft.^{3}) Nominal 2.2

RATED MAXIMUM TEMPERATURE (°F) 400

TENSILE STRENGTH 28 psi Parallel
20 psi Perpendicular

BLOWING AGENT Fluorocarbon

AGING CHARACTERISTICS 4% Growth Volume at 392° for 1 Day

K (BTU-In./Hr.-Sq. Ft.-°F) .132 at 70-75°

OUTGASSING TEMPERATURE 350

FIRE RATING: FLAME SPREAD)
)
FUEL CONTRIBUTED) ASTM 1692-59T Non-Burning Flame,
) Bureau of Mines, Penetration Test,
SMOKE DEVELOPED) Minutes/Inch - 17 Minutes

COST	PER POUND	PER SQUARE FOOT COLLECTOR (R = 10 at 75°)
100	~ .88	
1,000		
10,000		
50,000		

COMMENT: API has been purchased by another company and is re-evaluating its intention to market 520-2.

FOAM

TYPE "LASL TYPE" CO_2 Urethane, BKC-44302-2

SOURCE Bendix, Kansas City Division, P.O. Box 1159
Kansas City, Missouri 64141, (816) 363-3211

DENSITY (Lb./Ft.^{3}) 2

RATED MAXIMUM TEMPERATURE (°F) 325

TENSILE STRENGTH

BLOWING AGENT CO_2

AGING CHARACTERISTICS

K (BTU-In./Hr.-Sq. Ft.-°F) .2 at 70-75°

OUTGASSING TEMPERATURE 240

FIRE RATING: FLAME SPREAD 25

FUEL CONTRIBUTED

SMOKE DEVELOPED

COST	PER POUND	PER SQUARE FOOT COLLECTOR (R = 10 at 75°)
100	~ .60-.70	
1,000		
10,000		
50,000		

COMMENT: In outgassing test, the material shriveled up unlike others.

FOAM

TYPE Isofoam RC-3 Urethane

SOURCE Witco Chemical, 900 Wilmington Road, Wilmington, Delaware 19720, (302)-328-5661

DENSITY (Lb./Ft.^{3}) 3.4

RATED MAXIMUM TEMPERATURE (°F) 300

TENSILE STRENGTH Approximately 30 to 40 psi

BLOWING AGENT Freon Spray

AGING CHARACTERISTICS 200°F 28 Days, 0 Volume Change

K (BTU-In./Hr.-Sq. Ft.-°F) .16 at 77

OUTGASSING TEMPERATURE 280-300

FIRE RATING: FLAME SPREAD)
FUEL CONTRIBUTED) Contains no Fire Retardants
SMOKE DEVELOPED)

COST	PER POUND	PER SQUARE FOOT COLLECTOR (R = 10 at 75°)
100	.89	
1,000		
10,000		
50,000		

COMMENT: Contains no fire retardants and thus would be unacceptable to major building codes.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

FOAM

TYPE	Rapco Foam - Urea-Formaldehyde
SOURCE	Raperswill Corporation, 305 E. 40th Street, New York, New York 10016 (212) 986-7030
DENSITY (Lb./Ft.^{3})	0.7
RATED MAXIMUM TEMPERATURE (°F)	210
TENSILE STRENGTH	Low
BLOWING AGENT	Not Available
AGING CHARACTERISTICS	Good resistance to aging, very little volume change
K (BTU-In./Hr.-Sq. Ft.-°F)	.2 at 70-75°
OUTGASSING TEMPERATURE	240
FIRE RATING: FLAME SPREAD	25
FUEL CONTRIBUTED	10
SMOKE DEVELOPED	0-5

COST	PER POUND	PER SQUARE FOOT COLLECTOR (R = 10 at 75°)
100		~.20
1,000		
10,000		
50,000		

COMMENT: Would provide no structural rigidity to frame.

FOAM

TYPE	Isoschaum Urea-Formaldehyde
SOURCE	Schaum Chemicals Ltd., P.O. Box 34268, Washington, D. C. 20034 (301) 770-4404
DENSITY (Lb./Ft.^{3})	0.7
RATED MAXIMUM TEMPERATURE (°F)	210
TENSILE STRENGTH	Low
BLOWING AGENT	Not Available
AGING CHARACTERISTICS	Good resistance to aging, very little volume change
K (BTU-In./Hr.-Sq. Ft.-°F)	.2 at 70-75°
OUTGASSING TEMPERATURE	280

FIRE RATING:

FLAME SPREAD	25
FUEL CONTRIBUTED	10
SMOKE DEVELOPED	0-5

COST	PER POUND	PER SQUARE FOOT COLLECTOR (R = 10 at 75°
100		~.20
1,000		
10,000		
50,000		

COMMENT: Would provide no structural rigidity to frame.

GLASS FIBERS

TYPE	Microlite
SOURCE	Johns-Manville, OEM Thermal and Acoustical Insulations, Greenwood Plaza, Denver, Colorado 80217
DENSITY	.6-2 lbs./ft.^{3}
RATED MAXIMUM TEMPERATURE	300
K (BTU-In./°F-Hr.-Ft.^{2})	.24-.3 at 100°
OUTGAS TEMPERATURE	390
COST PER SQUARE FOOT COLLECTOR (R = 10 at 75°)	~.20
100	
1,000	
10,000	
50,000	

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

GLASS FIBERS

TYPE	Glasfleece
SOURCE	Carney and Associates, P.O. Box 1237, Mankato, Minnesota 56001, (507) 345-5035
DENSITY	2.75-6 lbs./ft.^{3}
RATED MAXIMUM TEMPERATURE	600
K (BTU-In./°F-Hr.-Ft.^{2})	.21-.25 at 75
OUTGAS TEMPERATURE	320
COST PER SQUARE FOOT COLLECTOR (R = 10 at 75°)	~.125
100	
1,000	
10,000	
50,000	

GLASS FIBERS

TYPE	Unbonded B - No Binder
SOURCE	Johns-Manville, OEM Thermal and Acoustical Insulations, Greenwood Plaza, Denver, Colorado 80217
DENSITY	1.5 when compressed - lbs./ft.^{3}
RATED MAXIMUM TEMPERATURE	850-1,000
K (BTU-In./°F-Hr.-Ft.^{2})	.25 at 100
OUTGAS TEMPERATURE	Over 400
COST PER SQUARE FOOT COLLECTOR (R = 10 at 75°)	~.80
100	
1,000	
10,000	
50,000	

GLASS FIBERS

TYPE	AWX-HT (1.25% Binder)	
SOURCE	Owens-Corning, Fiberglas Tower, Toledo, Ohio 43659, (419) 259-3000	
DENSITY		
RATED MAXIMUM TEMPERATURE	1,000	
K (BTU-In./°F-Hr.-Ft.^{2})	.33 at 150°	
OUTGAS TEMPERATURE		
COST PER SQUARE FOOT COLLECTOR (R = 10 at 75°)		~.12 to .15 in carloads (90,000 Bd. Ft.)
100		
1,000		
10,000		
50,000		

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

GLASS FIBERS

TYPE	AWX-SR (2.5% Binder)
SOURCE	Owens-Corning, Fiberglas Tower, Toledo, Ohio 43659, (419) 259-3000
DENSITY	
RATED MAXIMUM TEMPERATURE	1,000
K (BTU-In./°F-Hr.-Ft.^{2})	.33 at 150
OUTGAS TEMPERATURE	340
COST PER SQUARE FOOT COLLECTOR (R = 10 at 75°)	~.12-.15 in carloads (90,000 bd. ft.)
100	
1,000	
10,000	
50,000	

GLASS FIBERS

TYPE	FRK 703
SOURCE	Owens-Corning, Fiberglas Tower, Toledo, Ohio 43659, (419) 259-3000
DENSITY	1.5-6 lbs./ft.^{3}
RATED MAXIMUM TEMPERATURE	450
K (BTU-In./°F-Hr.-Ft.^{2})	.22-.24 at 75
OUTGAS TEMPERATURE	270
COST PER SQUARE FOOT COLLECTOR (R = 10 at 75°)	.46
100	
1,000	
10,000	
50,000	

GLASS FIBERS

TYPE IS Board

SOURCE Owens-Corning, Fiberglas Tower, Toledo, Ohio 43659, (419) 259-3000

DENSITY 3 lbs./ft.^{3}

RATED MAXIMUM TEMPERATURE 850

K (BTU-In./°F-Hr.-Ft.^{2}) .25 at 100

OUTGAS TEMPERATURE 340

COST PER SQUARE FOOT COLLECTOR (R = 10 at 75°) .40

100

1,000

10,000

50,000

GLASS FIBERS

TYPE	TIW
SOURCE	Owens-Corning, Fiberglas Tower, Toledo, Ohio 43659, (419) 259-3000
DENSITY	1-2.5 lbs./ft.^{3}
RATED MAXIMUM TEMPERATURE	1,000
K (BTU-In./°F-Hr.-Ft.^{2})	.15-.20 at 100
OUTGAS TEMPERATURE	Over 350
COST PER SQUARE FOOT COLLECTOR (R = 10 at 75°)	.19
100	
1,000	
10,000	
50,000	

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

MINERAL/CERAMIC FIBERS, MISCELLANEOUS INSULATIONS

TYPE Foamglas - Cellular Glass

SOURCE Pittsburgh Corning, 1 Gateway Center, Pittsburgh, Pennsylvania 15222
(412) 261-2900

DENSITY 8 lbs./ft.^{3}

RATED MAXIMUM TEMPERATURE Over 400

K (BTU-In./°F-Hr.-Ft.^{2}) .37 at 75

OUTGAS TEMPERATURE Over 400

COST PER SQUARE FOOT COLLECTOR (R = 10 at 75°) $.982

100

1,000

10,000

50,000

MINERAL/CERAMIC FIBERS, MISCELLANEOUS INSULATIONS

TYPE	PV Supertemp Block, Mineral Fiber
SOURCE	Eagle Picher, Fibers Department, P.O. Box 779, Cincinnati, Ohio 45201
DENSITY	15 lbs/ft.^{3}
RATED MAXIMUM TEMPERATURE	1,900
K (BTU-In./°F-Hr.-Ft.^{2})	.28 at 200
OUTGAS TEMPERATURE	
COST PER SQUARE FOOT COLLECTOR (R = 10 at 75°)	~.96
100	
1,000	
10,000	
50,000	

MINERAL/CERAMIC FIBERS, MISCELLANEOUS INSULATIONS

TYPE	MT Board Mineral Fiber
SOURCE	Eagle Picher, Fibers Department, P.O. Box 779, Cincinnati, Ohio 45201
DENSITY	6-10 lbs./ft.^{3}
RATED MAXIMUM TEMPERATURE	1,050
K (BTU-In./°F-Hr.-Ft.^{2})	~.22 at 100
OUTGAS TEMPERATURE	320
COST PER SQUARE FOOT COLLECTOR (R = 10 at 75°)	~ .16
100	
1,000	
10,000	
50,000	

MINERAL/CERAMIC FIBERS, MISCELLANEOUS INSULATIONS

TYPE	Mineral Fiber Blanket
SOURCE	Keene Corporation, Insulation Division, P.O. Box 145 Princeton, New Jersey 08540, (609) 452-8090
DENSITY	10 lbs./ft.^{3}
RATED MAXIMUM TEMPERATURE	1,200
K (BTU-In./°F-Hr.-Ft.^{2})	.25 at 100
OUTGAS TEMPERATURE	Over 400
COST PER SQUARE FOOT COLLECTOR (R = 10 at 75°)	~.30
100	
1,000	
10,000	
50,000	

MINERAL/CERAMIC FIBERS, MISCELLANEOUS INSULATIONS

TYPE	Mono-Block Mineral Fiber
SOURCE	Keene Corporation, Insulation Division, P.O. Box 145, Princeton, New Jersey 08540, (609) 452-8090
DENSITY	13 lbs./ft.^{3}
RATED MAXIMUM TEMPERATURE	1,900
K (BTU-In./°F-Hr.-Ft.^{2})	.36 at 200
OUTGAS TEMPERATURE	Over 410
COST PER SQUARE FOOT COLLECTOR (R = 10 at 75°)	~.90
100	
1,000	
10,000	
50,000	

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MINERAL/CERAMIC FIBERS, MISCELLANEOUS INSULATIONS

TYPE Therma-K Mineral Wool

SOURCE Keene Corporation, Insulation Division, P.O. Box 145, Princeton, New Jersey 08540, (609) 452-8090

DENSITY 8 lbs./ft.^{3}

RATED MAXIMUM TEMPERATURE 1,000

K (BTU-In./°F-Hr.-Ft.^{2}) .30 at 200

OUTGAS TEMPERATURE Over 400

COST PER SQUARE FOOT COLLECTOR (R = 10 at 75°) ~.28

100

1,000

10,000

50,000

MINERAL/CERAMIC FIBERS, MISCELLANEOUS INSULATIONS

TYPE	Thermasil - Calcium Silicate
SOURCE	Keene Corporation, Insulation Products Division, P.O. Box 145, Princeton, New Jersey 08540, (609) 452-8090
DENSITY	13 lbs./ft.^{3}
RATED MAXIMUM TEMPERATURE	1,200
K (BTU-In./°F-Hr.-Ft.^{2})	.33 at 100
OUTGAS TEMPERATURE	Over 390
COST PER SQUARE FOOT COLLECTOR (R = 10 at 75°)	~1.80
100	
1,000	
10,000	
50,000	

MINERAL/CERAMIC FIBERS, MISCELLANEOUS INSULATIONS

TYPE Fiberfrax Blanket - Ceramic Fiber

SOURCE Fiberfrax Branch, Carborundum, P.O. Box 808, Niagra Falls, New York 14302, (716) 278-2674

DENSITY 4-6 lbs./ft.^{3}

RATED MAXIMUM TEMPERATURE 2,300

K (BTU-In./°F-Hr.-Ft.^{2}) ~.35 at 400

OUTGAS TEMPERATURE

COST PER SQUARE FOOT COLLECTOR (R = 10 at 75°) ~ 4.00

100

1,000

10,000

50,000

MINERAL/CERAMIC FIBERS, MISCELLANEOUS INSULATIONS

TYPE Kaowool Blanket, Ceramic Fiber

SOURCE Babcock and Wilcox, Refractories Division, P.O. Box 923, Augusta, Georgia 30903, (404) 798-8000

DENSITY 3-8 lbs./ft.^{3}

RATED MAXIMUM TEMPERATURE 2,300

K (BTU-In./°F-Hr.-Ft.^{2}) .25-.30 at 400

OUTGAS TEMPERATURE Over 400

COST PER SQUARE FOOT COLLECTOR (R = 10 at 75°) ~ 4.00

100

1,000

10,000

50,000

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

MINERAL/CERAMIC FIBERS, MISCELLANEOUS INSULATIONS

TYPE WRP-X Ceramic Fiber

SOURCE Refractory Products, 500 W. Central Road, Mt. Prospect, Illinois 60056 (312) 255-6300

DENSITY

RATED MAXIMUM TEMPERATURE 2,300

K (BTU-In./°F-Hr.-Ft.^{2}) .38 at 500

OUTGAS TEMPERATURE Over 410

COST PER SQUARE FOOT COLLECTOR (R = 10 at 75°)

100	~12.00
1,000	12.00
10,000	12.00
50,000	12.00

MINERAL/CERAMIC FIBERS, MISCELLANEOUS INSULATIONS

TYPE Insblock-12 Mineral Wool

SOURCE A. P. Green Refractories, Mexico, Missouri 65265, (314) 581-5000

DENSITY 8-10 lbs./ft.^{3}

RATED MAXIMUM TEMPERATURE 1,200

K (BTU-In./°F-Hr.-Ft.^{2}) .27 at 200

OUTGAS TEMPERATURE

COST PER SQUARE FOOT COLLECTOR (R = 10 at 75°) .73

100

1,000

10,000

50,000

MINERAL/CERAMIC FIBERS, MISCELLANEOUS INSULATIONS

TYPE Insblock-19 Mineral Wool

SOURCE A.P. Green Refractories, Mexico, Missouri 65265, (314) 581-5000

DENSITY 19-20 lbs./ft.3

RATED MAXIMUM TEMPERATURE 1,900

K (BTU-In./°F-Hr.-Ft.^{2}) .34 at 200

OUTGAS TEMPERATURE

COST PER SQUARE FOOT COLLECTOR (R = 10 at 75°) 1.63

100

1,000

10,000

50,000

APPENDIX H

INSULATION THERMAL/PHYSICAL CHARACTERISTICS

TABLE H-1

FOAMS

PRODUCT	MANUFACTURER	TYPE	BLOWING AGENT	RATED MAX. TEMP. (°F)	DENSITY (Lb./Ft.^{3})	K (BTU-in./Ft.^{2}-°F-Hr.)	COST (Bd. Ft.)	OUTGAS TEMP. (°F)
1. RAPCO Foam	Rapperswill Corporation, 305 E. 40th Street, New York, New York 10016, (212) 986-7030	Urea-Formaldehyde	--	210	0.7	.2 at 70-75	.10	240
2. Isoschaum	Schaum Chem. Ltd., P.O. Box 34268, Washington, D. C. 20034, (301) 770-4404	Urea-Formaldehyde	--	210	0.7	.2 at 70-75	.10	280
3. 520-2	API Systems, 11034 Sutter Avenue, Pacoima, California 91331, (213) 899-2583	Urethane	Freon	400	'2.2' Actually About 4.0	.132 at 70-75	~.30	350
4. UFC 175	United Foam Corporation, 19201 S. Reyes Avenue, Compton, California 90221, (213) 774-5600	Isocyanurate	Freon	400	2.6	.13 at 70-75	~.15 (At 2.6 Density)	
5. UFC 160	United Foam Corporation	Urethane	Freon	300	2.0	.13 at 70-75	~.13	
6. CPR 421	Upjohn CPR Division, 555 Alaska Avenue, Torrance, California 90503, (213) 320-3550	Isocyanurate	Freon	375	2.0	.15 at 70-75		
7. Isofoam RC-3	Witco Chemical, 900 Wilmington Road, Wilmington, Delaware 19720 (Chicago) (312) 644-7200	Urethane	CO_2	300	3.4	.16 at 70-75		280
8.	Bendix, Kansas City Division, P. O. Box 1159, Kansas City, Missouri 64141, (816) 363-3211	Urethane	CO_2	325		.20 at 70-75	'.60-.70 per lb. in large quantities' ≈.23 for 4 lb./ft.^{3}	
9. Rubifroth (Typical Values)	Uniroyal, Rubicon Chemicals, Elm Street, Naugatuck, Connecticut 06770 (203) 723-3749	Isocyanurate	Freon	300	2.0	.16 at 70-75		220

H-1

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

TABLE H-2

FIBERGLASSES

PRODUCT	MANUFACTURER	MAX. TEMP. (°F)	DENSITY	K (BTU-in./ °F-Ft.^{2}-Hr.)	COST (Bd. Ft.)	OUTGAS TEMP. (°F)
1. Microlite	Johns-Manville, OEM Thermal and Acoustical Insulations, Greenwood Plaza, Denver, Colorado 80217	300	.6-2	.24-.3 at 100	~.08	390
2. Unbonded B	Johns-Manville	850-1,000	1.5	.25 at 100	.32 (Fully Compressed)	>400
3. Glasfleece	Carney and Associates, P.O. Box 1237, Mankato, Minnesota 56001 (507) 345-5035	600	2.75-6	.21-.25 at 75	.05	320
4. AWX-SR (2.5% Binder)	Owens-Corning, Fiberglass Tower, Toledo, Ohio 43659, (419) 259-3000	1,000	--	.33 at 150	4-5¢ in Carloads (90,000 Bd. Ft.)	340
5. AWX-HT (1.25% Binder)	Owens-Corning	1,000	--	.33 at 150	4-5¢ in Carloads (90,000 Bd. Ft.)	
6. FRK 703	Owens-Corning	450	1.5-6	.22-.24 at 75		270
7. IS Board	Owens-Corning	850	3	.25 at 100		340
8. TIW	Owens-Corning	1,000	1-2.5	.15-2 at 100		>350

TABLE H-3

MINERAL/CERAMIC FIBERS

PRODUCT	MANUFACTURER	MATERIAL	MAX. TEMP. (°F)	DENSITY (Lb./Ft.^{3})	K (BTU-in./Ft.^{2}-°F-Hr.)	COST (Bd. Ft.)	CUTGAS TEMP. (°F)
1. Insblock-19	A. P. Green Refractories, Mexico, Missouri 65265, (314) 581-5000	Mineral Wool	1,900	19-20	.34 at 200		
2. Insblock-12	A. P. Green Refractories	Mineral Wool	1,200	8-10	.27 at 200		
3. WRP-X	Refractory Products, 500 W. Central Rd., Mt. Prospect, Illinois 60056, (312) 255-6300	Ceramic Fiber	2,300		.38 at 500	6.00	>410
4. Kaowool Blanket	Babcock and Wilcox, Refractories Division, P.O. Box 923, Augusta, Georgia 30903, (404) 798-8000	Ceramic Fiber	2,300	3-8	.25-.3 at 400	.59	
5. Fiberfrax Blanket	Carborundum, Refractories and Insulation Division, Fiberfrax Branch, P.O. Box 808, Niagara Falls, New York 14302 (716) 278-2674	Ceramic Fiber	2,300	4-6	~.35 at 400	1.58	
6. Thermasil	Keene Corporation, Insulation Division, P.O. Box 145, Princeton, New Jersey 08540, (609) 452-8090	Calcium Silicate	1,200	13	.33 at 100	.60	>390
7. Mono-Block	Keene Corporation	Mineral Wool	1,900	13	.36 at 200		>410
8. Therma-K	Keene Corporation	Mineral Wool	1,000	8	.30 at 200	.11	>400
9. Mineral Fiber Blanket	Keene Corporation	Mineral Wool	1,200	10	.25 at 100	.12	>400
10. MT Board	Eagle Picher, Fibers Dept., P.O. Box 779, Cincinnati, Ohio 45201	Mineral Fiber	1,050	6-10	~.22 at 100	.08	320
11. 'PV' Supertemp Block	Eagle Picher	Mineral Fiber	1,900	16	.28 at 200	.38	
12. Foamglas	Pittsburgh Corning, 1 Gateway Center, Pittsburgh, Pennsylvania 15222, (412) 261-2900	Foamed Glass	>400	8	.37 at 75		

APPENDIX I

MOLDING AND GASKET MATERIALS

MOLDING AND GASKET MATERIAL

TYPE Silastic(R) 732 RTV Adhesive/Sealant
(One part vulcanizing silicone rubber)

SOURCE Dow Corning Corporation
Midland, Michigan 48640

DUROMETER 25A

ULTRA-VIOLET RESISTANCE Excellent resistance to weathering, moisture, ozone and sunlight.

AGING CHARACTERISTICS Peel strength remains constant after 60 days at 302°F. Elongation after 60 days at 302°F is almost the same as the original.

LIMITATIONS -100 to +450°F. 10-20 minutes tack free time
Cure Time - 24 hours (1/8 inch thickness)
Acetic acid given off during cure.

OUTGASSING CHARACTERISTICS

COST $25.00/gallon

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MOLDING AND GASKET MATERIAL

TYPE	Silastic[(R)] 738 RTV Adhesive/Sealant One part silicone rubber
SOURCE	Dow Corning Corporation Midland, Michigan 48640
DUROMETER	25A
ULTRA-VIOLET RESISTANCE	Resistance to ozone, weathering
AGING CHARACTERISTICS	Still rubbery after 12 months at 360°F
LIMITATIONS	Tack tree time - 2 hours. Temperature - -85 to +360°F. No corrosive by-products. Cure Time - 7 days.
OUTGASSING CHARACTERISTICS	
COST	$25.00/gallon

MOLDING AND GASKET MATERIAL

TYPE TPC-101

One part polysulfide sealant

SOURCE Thorson Polymer Corporation
299 Park Avenue
New York, New York 10017

DUROMETER 20-30A

ULTRA-VIOLET RESISTANCE Excellent to weather, sunlight, ozone, water.

AGING CHARACTERISTICS Life Expectancy - 20 years

LIMITATIONS Temperature - -60° to +212°F. Cure Time - 2 weeks

OUTGASSING CHARACTERISTICS

COST $17.50/gallon

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MOLDING AND GASKET MATERIAL

TYPE Pecora 862 Silicone Architectural Sealant
1 part silicone

SOURCE. Pecora Chemical Corporation
300-400 West Sedgley Avenue
Philadelphia, PA 19140 (215-739-6130)

DUROMETER 25A

ULTRA-VIOLET RESISTANCE

"(It) is impervious to the effects of sunlight, rain, snow, ozone and temperature extremes."

AGING CHARACTERISTICS

Life Expectancy - 10-20 years

"Its elongation, tensile strenght, hardness, and adhesion do not change with age or weather."

LIMITATIONS

Practical service range = -80 to +250°F. It does not soften with heat at 350°F.

OUTGASSING CHARACTERISTICS

COST $25.00/gallon

MOLDING AND GASKET MATERIAL

TYPE	Synthacalk GC-9 One part polysulfide base synthetic rubber sealant
SOURCE	Pecora Chemical Corporation 300-400 West Sedgley Avenue Philadelphia, PA 19140 (215-739-6130)
DUROMETER	35-40A
ULTRA-VIOLET RESISTANCE	No degradation
AGING CHARACTERISTICS	Life Expectancy - 10-20 years
LIMITATIONS	-20 to 180°F 72-96 hours tack free time
OUTGASSING CHARACTERISTICS	
COST	$19.00/gallon

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

MOLDING AND GASKET MATERIAL

TYPE	Pecora GC-5 Two part polysulfide base synthetic rubber sealant
SOURCE	Pecora Chemical Corporation, 300-400 West Sedgley Avenue, Philadelphia, Pennsylvania 19140 (215-739-6130)
DUROMETER	35A
ULTRA-VIOLET RESISTANCE	No Degradation
AGING CHARACTERISTICS	Life Expectancy 10-20 Years
LIMITATIONS	-20 to +180°F 48-72 hours tack free time
OUTGASSING CHARACTERISTICS	
COST	$15.00/gallon

MOLDING AND GASKET MATERIAL

TYPE	Weatherban(R) 202 Sealant
SOURCE	Adhesives, Coatings and Sealers Division 3M Company 3M Center St. Paul, Minnesota 55101 (612-733-1110)
DUROMETER	
ULTRA-VIOLET RESISTANCE	After 1,000 hours exposure to Sunshine Arc Weatheromerer - sealant was rated 'good'
AGING CHARACTERISTICS	
LIMITATIONS	-50 to 160°F continuous exposure to 250°F for 1 hour Tack free time - 2 hours Shrinkage of 30%
OUTGASSING CHARACTERISTICS	
COST	5 Gallon Pails — \$10.41/gallon (1-9 Pails) \$ 8.85/gallon (10+)

MOLDING AND GASKET MATERIAL

TYPE	Novacalk 200, Two Part Polysulfide
SOURCE	Novagard Corporation, 835 New York Avenue Trenton, New Jersey 08638 (609-695-6194)
DUROMETER	20-25A
ULTRA-VIOLET RESISTANCE	Fair
AGING CHARACTERISTICS	Hardens with age, life expectancy unknown.
LIMITATIONS	36 hours tack free time, -40 to +200°F temperature range.
OUTGASSING CHARACTERISTICS	N/A
COST	$13.04/gallon (Black) more for other colors

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MOLDING AND GASKET MATERIAL

TYPE Novacalk 300, One Part Latex Base, Acrylic Polymer

SOURCE Novagard Corporation, 835 New York Avenue
Trenton, New Jersey 08638 (609-695-6194)

DUROMETER N/A

ULTRA-VIOLET RESISTANCE Fair

AGING CHARACTERISTICS Hardens with age, life expectancy unknown.

LIMITATIONS 20 minute tack free time, -20 to +180°F temperature range.

OUTGASSING CHARACTERISTICS Unknown

COST $.86/cartridge (11 oz.)

MOLDING AND GASKET MATERIAL

TYPE	Novacalk 400, One Part Butyl Blend
SOURCE	Novagard Corporation, 835 New York Avenue Trenton, New Jersey 08638 (609-695-6194)
DUROMETER	N/A
ULTRA-VIOLET RESISTANCE	Fair
AGING CHARACTERISTICS	Hardens with age, 20-year life expectancy.
LIMITATIONS	One hour tack free time, -20 to +180°F temperature range.
OUTGASSING CHARACTERISTICS	Unknown
COST	$.60/cartridge (11 oz.)

MOLDING AND GASKET MATERIAL

TYPE Novatherm (TM) 415

1 part butyl Hot Melt Sealant

SOURCE Novagard Corporation
835 New York Avenue
Trenton, New Jersey 08638 (609-695-6194)

DUROMETER 30A

ULTRA-VIOLET RESISTANCE Good resistance to UV and moisture

AGING CHARACTERISTICS Expected lifetime 20 years

LIMITATIONS Tack free time 10 minutes.
Temperature Range - -100°F to +325°F

OUTGASSING CHARACTERISTICS

COST $13.00/gallon plus $12,000 tooling cost

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MOLDING AND GASKET MATERIAL

TYPE — Novacalk 600

One part polysulfide base   Building sealant

SOURCE — Novagard Corporation
835 New York Avenue
Trenton, New Jersey 08638 (609-695-6194)

DUROMETER — 25A

ULTRA-VIOLET RESISTANCE

AGING CHARACTERISTICS

LIMITATIONS — -40 to +220°F

Tack free time - 4-8 hours
Cure time - 20 days

OUTGASSING CHARACTERISTICS

COST — $15.91/gallon (Black) more for other colors
$1.67/cartridge (11 oz.) (any color)

MOLDING AND GASKET MATERIAL

TYPE MONO(R)

1 part acrylic terpolymer sealant

SOURCE Tremco Manufacturing Company
10701 Shaker Boulevard
Cleveland, Ohio 44104
(216-229-3000)

DUROMETER 40-50A (after 3 years exterior exposure)

ULTRA-VIOLET RESISTANCE

Excellent resistance to UV, oxygen and moisture.

AGING CHARACTERISTICS Expected Lifetime - 20 years

LIMITATIONS Tack Free Time - 24-72 hours

OUTGASSING CHARACTERISTICS

Slowly outgasses as it cures over the years.

COST $7.25/gallon

MOLDING AND GASKET MATERIAL

TYPE Dymeric(R)
2 part polytremdyne terpolymer sealant

SOURCE Tremco Manufacturing Company
10701 Shaker Boulevard
Cleveland, Ohio 44104
(216-229-3000)

DUROMETER 25-35A

ULTRA-VIOLET RESISTANCE Resists UV, ozone and moisture

AGING CHARACTERISTICS Expected Lifetime - 25 years
Accelerated aging test ASTM-E-42 Method E - no significant changes after 8,000 hours.

LIMITATIONS Tack Free Time - 2 days

OUTGASSING CHARACTERISTICS

COST $13.60/gallon

MOLDING AND GASKET MATERIAL

TYPE	Lasto-Meric (R) Two component polysulfide sealant
SOURCE	Tremco 1701 Shaker Boulevard Cleveland, Ohio 44104 (216-229-3000)
DUROMETER	25-30 A
ULTRA-VIOLET RESISTANCE	Good resistance to UV and moisture
AGING CHARACTERISTICS	Life expectancy 20 years. No significant changes in characteristics after 5,000 hours in weatherometer.
LIMITATIONS	Service temperature range - -60°F to +225°F. Initial cure 15 hours at 70°F.
OUTGASSING CHARACTERISTICS	
COST	$20.60/gallon

MOLDING AND GASKET MATERIAL

TYPE Tremco 440 Tape

100% solids, polyisobutylene-butyl, preformed sealant
Also available pre-shimmed

SOURCE
Tremco
10701 Shaker Boulevard
Cleveland, Ohio 44104 (216-279-3000)

DUROMETER 20-30 A

ULTRA-VIOLET RESISTANCE "Unaffected by UV through glass"

AGING CHARACTERISTICS

After 1,000 hours exposure in accelerated aging unit (6-10 years exposure) adhesion was still excellent.

LIMITATIONS Service Temperatures - -40°F to +220°F
Adhesive on one side.

OUTGASSING CHARACTERISTICS

Specimen conditioned at 275°F showed no oil exudation. 100% solids - no solvents to vaporize.

COST 5.26¢ per foot (1/8 inch by 1/2 inch)

MOLDING AND GASKET MATERIAL

TYPE Polyshim (TM) Tape

A macro-polyisobutylene preformed tape

SOURCE Tremco, 10701 Shaker Boulevard, Cleveland, Ohio 44104
(216-279-3000)

DUROMETER

ULTRA-VIOLET RESISTANCE Excellent resistance to sunlight

AGING CHARACTERISTICS

Adhesion improves with age, 20 years minimum life expectancy. Adhesion excellent after 1,000 hours accelerated aging.

LIMITATIONS -60°F to +225°F

OUTGASSING CHARACTERISTICS

COST $.11/ft (3/16 inch by 1/2 inch)

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MOLDING AND GASKET MATERIAL

TYPE Strip-N-Stick(R)

Silicone Sponge Rubber Tape

SOURCE

Connecticut Hard Rubber Company
407 East Street
New Haven, Connecticut 06509 (203-777-3631)

DUROMETER

ULTRA-VIOLET RESISTANCE

AGING CHARACTERISTICS

LIMITATIONS Temperature Range - 100°F to 500°F

OUTGASSING CHARACTERISTICS

COST 1/8" thick, 1/2" width, 10 yard rolls - $8.30/roll

MOLDING AND GASKET MATERIAL

TYPE Nordel(R)
EPDM Rubber

SOURCE E. I. DuPont de Nemours and Company, Inc.
Elastomer Chemicals Department
Wilmington, Delaware 19898

DUROMETER 30-90A

ULTRA-VIOLET RESISTANCE Excellent

Ozone resistance - excellent.

AGING CHARACTERISTICS Excellent

LIMITATIONS Maximum temperature - 250-300°F. Special Formulations to 350°F. Low Temperature to -6°. Tensile Strength to 3,500 psi.

OUTGASSING CHARACTERISTICS

COST Depends on formulation, extrusion costs.

MOLDING AND GASKET MATERIAL

TYPE Epcar$^{(R)}$306

EPDM Rubber

SOURCE B. F. Goodrich Chemical Company
6100 Oak Tree Boulevard
Cleveland, Ohio 44131

DUROMETER 30-100A

ULTRA-VIOLET RESISTANCE Excellent.

Ozone resistance - excellent.

AGING CHARACTERISTICS Excellent

LIMITATIONS

Minimum continuous temperature -65°. Maximum 300°F.

Good resistance to glycols.

Tensile strength - 1,000-3,200 psi

OUTGASSING CHARACTERISTICS

COST Depends on formulation, extrusion costs.

TABLE I-1. SEALANTS: MANUFACTURERS AND PROPERTIES

MANUFACTURE	Novagard	Novagard	Novagard	Novagard	Novagard	Novagard
PRODUCT NAME	Novacalk 200 2 Parts	Novacalk 300 1 Part	Novacalk 400 1 Part	Novatherm 415 1 Part	Novacalk 444 Hot Melt 1 Pt	Novacalk 600 1 Part
BASE MATERIAL	Polysulfide	Laytex Base Acrylic Polymer	Butyl Blend	Butyl	Butyl Blend	Polysulfide
TACK FREE TIME	36 hours	20 minutes	1 hour	10 minutes	1 hour	4-8 hours
HARDNESS	20-25A			30A		25A
TENSILE	125					140
ELONGATION	800%		25%		25%	800%
PEEL-GLASS	25 ppi			10-12 ppi		20 ppi
PEEL-ALUMINUM	22 ppi				20 ppi	22 ppi
SHRINKAGE	None	None	15% max.	None	15% max.	None
SERVICE TEMP. °F	-40 +200	-20 +180	-20 +180	-100 +325	-20 +180	-40 +200
VISCOSITY	Non-Sag	Non-Sag	Non-Sag	Non-Sag	Non-Sag	Non-Sag
LIFE EXPECTANCY (YRS)			20 years	20 years	20 years	
SOLVENT						
MISC						
COST/GAL				$13.00*		
NOTES	Will Age Harden	Will Age Harden	Will Age Harden	*$12,000 Tooling Cost Melt Temp.	Will Age Harden	Will Age Harden

TABLE I-1 (CONTINUED)

MANUFACTURE	Dow Corning	Dow Corning	Thorson	Pecora	Pecora	Pecora	3M
PRODUCT NAME	Silastic 732	Silastic 738	TPC-101	862	GC-9	GC-5	Weatherban 202
BASE MATERIAL	Silicone 1 Part	Silicone 1 Part	Polysulfide 1 Part	Silicone 1 Part	Polysulfide 1 Part	Polysulfide 2 Parts	Synthetic Elastomer
TACK FREE TIME	10-20 min.	2 hours		1/2-1 hour	72-96 hr. amb. 120°F = 12+8 hr	48-72 hr. amb. 120°F = 12-18hr	2 hours
HARDNESS	25A	25A	20-30A	25A	35A	35A	
TENSILE	274 psi	275 psi	60 psi	275 psi	NA	NA	
ELONGATION	450%	400%	85%	325%	350% min.	350% min.	
PEEL-GLASS	15 ppi		25 ppi	10 ppi min.	10 ppi min.	10 ppi min.	5.0
PEEL-ALUMINUM	15 ppi	16	25 ppi	30 ppi min.	20 ppi min.	20 ppi min.	4.5
SHRINKAGE			None	3% max.	3% max.	3% max.	30%
SERVICE TEMP. °F	-100 +450	-85 +360	-60 +212	-80 +250	-20 +180	-20 +180	-50 +160 250 for 1 hr.
VISCOSITY	Non-Sag	Non-Sag	Non-Sag	Non-Sag	Non-Sag	Non-Sag	30,000 poise
LIFE EXPECTANCY (YRS)			20 years	10-20 years	10-20 years	10-20 years	
SOLVENT							Aromatic
MISC							
COST/GAL	$25.00		$17.50	$25.00	$19.00	$15.00	
NOTES	40 lbs. = $2.93/lb.						

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TABLE I-1 (CONTINUED)

MANUFACTURE	Tremco	Tremco	Tremco	Tremco	Tremco	Connecticut Hard Rubber	duPont	Goodrich
PRODUCT NAME	Mono	Dymeric	Lasto-Meric	440 Tape	Polyshim Tape	Strip-N-Stick	Nordel	Epcar 306
BASE MATERIAL	Acrylic 1 Part	2 Parts	Polysulfide 2 Parts	Butyl	Butyl	Silicone Sponge	EPDM Rubber	EPDM Rubber
TACK FREE TIME	24-72 hours							
HARDNESS	40-50A	25A	25-30A	20-30A			30-90A	30-100A
TENSILE							3,500 psi	1-3,000 psi
ELONGATION	300-400% at 20°F	300-500%	200-400%	Over 350%				
PEEL-GLASS	)15-20 lbs.	14 lbs.	27 ppi					
PEEL-ALUMINUM	)	15 lbs.	30 ppi					
SHRINKAGE			3%					
SERVICE TEMP. °F			-60 +225	-40 +200	-60 +225	-100 +500	-10 +350	-65 +300
VISCOSITY								
LIFE EXPECTANCY (YRS)	20 years min.	25 years	20 years				20 years	20 years
SOLVENT								
MISC								
COST/GAL								
NOTES	Highly Weather Resistant					1/8" Thick x 1/2" Wide Roll at $8.30/Roll		

APPENDIX J

SEALANT/GASKET OUTGASSING CHARACTERISTICS

The current designs for solar collectors involve the use of certain sealants and glazing strip materials which may outgas. Such outgassing could condense on the collector window and thus reduce its transmissivity. It is therefore desirable to use materials which will not outgas at operational or stagnation temperatures.

The objective of this test was to compare five possible sealants and two possible glazing strip materials for outgassing characteristics.

Samples of each were secured, and in the case of the sealants, samples were poured and allowed to cure. The samples were placed in beakers which had watch glasses covering them, and heated on a hot plate. A thermometer was placed in the beaker to record the temperature. The samples were heated until gas was given off or until the sample exhibited a major physical change. The watch glass served as a condensing surface similar to the collector cover(s).

Results:

Material	Outgas Temperature	Comments
Silastic® 732 RTV	290°F	Considerable gas, no other noticeable change in material.
3M Weatherban® 202	None at 240°F	Became very soft and started to flow.
Thorson TPC 101	270°F	Outer skin stayed tough, inside became mushy.
Pecora 862	300°F	No other noticeable change in material.
3M Metal Sealant 1814	280°F	Deformed at 120°F.
EPDM (DuPont Nordel)	270°F	No other noticeable change in material.
Silicone Rubber	270°F	No other noticeable change in material.

Both EPDM and silicone outgas at the same temperature so if everything else is equal,EPDM is the choice on cost (silicone is seven times more expensive). Pecora has the best characteristics of the sealants.

APPENDIX K

DESICCANTS

K-1

DESICCANT

TYPE Du-Cal Drierite - $CaSO_4$ + $CaCl_2$ absorbent

SOURCE W. A. Hammond Drierite Company
Xenia, Ohio
(513) 376-2927

CAPACITY 26.5% Lbs. Water Absorbed/100 Lbs. Dry Desiccant

REGENERATION 375-400°F for 1-2 hours

LIFE CYCLE Indefinite

CONTAINERS FOR PACKAGING Bags and balance desiccator (2.75) available from W. A. Hammond.

4 ounce bag is 4" x 6" cost 11 cents in quantities. Balance desiccator holds 150 grams of 4-mesh Drierite.

WEIGHT NECESSARY FOR COLLECTOR .15 lb.

COST PER COLLECTOR	Desiccant Only
100	4 cents
1,000	4 cents
10,000	4 cents
50,000	4 cents

COMMENT: Regeneration at 375 makes it unsuitable.

DESICCANT

TYPE	Drierite $CaSO_4$ Absorbent
SOURCE	W. A. Hammond Drierite Company, Xenia, Ohio, (513) 376-2927
CAPACITY	10% lbs. of H_2O/100 lbs. dry desiccant Our tests showed sorption of 3.6% after 48 hours of outdoor exposure.
REGENERATION	375-400°F for 1-2 hours Our tests showed desorption of 16.5% after 6 hours at 130°F.
LIFE CYCLE	Indefinite
CONTAINERS FOR PACKAGING	W. A. Hammond can supply desiccant cloth bags. The 8 ounce size costs 19 cents. Also available is a balance desiccator for 2.75. It holds 150 grams of 4-mesh Drierite.

WEIGHT NECESSARY FOR COLLECTOR

.63

COST PER COLLECTOR - Desiccant Only

100	66 cents
1,000	14 cents
10,000	14 cents
50,000	14 cents

COMMENT: Regeneration at 375 makes it unsuitable.

DESICCANT

TYPE Silica Gel - Balance Desiccator/Air Dryer

SOURCE

Fisher Scientific (Small Qty.)
1458 N. Lamon Avenue
Chicago, Illinois 60651
(312) 379-9300

W. R Grace, Davison Chemical*
10 East Baltimore Street
Baltimore, Maryland 21203
(301) 727-3900

CAPACITY

40% lbs. of H_2O adsorbed/100 lbs. of dry desiccant
Our tests showed sorption of 8% after 48 hours of outdoor exposure.

REGENERATION Our tests showed desorption of 28% after 6 hours at 130°F to completely regenerate heat to 250-400°F and purge with clean gas.

LIFE CYCLE Indefinite

CONTAINERS FOR PACKAGING Packaged
Perforated Canister 2-3/4" Diameter x 0.6" Deep

WEIGHT NECESSARY FOR COLLECTOR ~.1 lb. (one container)

COST PER COLLECTOR

100	2.70 (Fisher)
1,000	0.80 (Hargo)
10,000	0.80 (Hargo)
50,000	0.80 (Hargo)

* Local Distributor: Hargo Corporation, 1755 Beech Hill, Dayton, Ohio 45439, (513) 293-2155, Mr. Van Winkle, Part No. X-1009.

COMMENT: Tests so far indicate it will perform well in the collector. The only one we know of which is conveniently packaged.

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DESICCANT

TYPE	Silica Gel - adsorbent
SOURCE	Eagle Chemical P.O. Box 107 Mobile, Alabama 36601 (205) 438-9781
CAPACITY	40% Lbs. of H_2O adsorbed/100 lbs. of dry desiccant Our tests showed sorption of 9.6% after 48 hours of outdoor exposure.
REGENERATION	Heat to 250-450°F and purge with a clean gas Our tests showed desorption of 23% after 6 hours at 130°F.
LIFE CYCLE	10,000 Cycles

CONTAINERS FOR PACKAGING

WEIGHT NECESSARY FOR COLLECTOR ~ .1 lb.

COST PER COLLECTOR

100	14.5 cents
1,000	10.5 cents
10,000	10.5 cents
50,000	9.5 cents

COMMENT: The best adsorbent.

DESICCANT

TYPE	Natrasorb(R) T - a hard, beaded, amorphous form of silica gel, adsorbent
SOURCE	Multiform Desiccant Products 1418 Niagra Street Buffalo, New York 14213 (716) 881-0100
CAPACITY	40% Lbs. of H_2O adsorbed/100 lbs. of dry desiccant Our tests showed sorption of 8.5% after 48 hours of outdoor exposure.
REGENERATION	Our tests showed desorption of 18% after 6 hours at 130°F to regenerate heat to 250°-450°F and purge with clean gas.
LIFE CYCLE	"Almost Indefinitely"

CONTAINERS FOR PACKAGING — Multiform can supply 4-1/2 x 4-1/2 x 1/2 bags for 9 cents each in quantities over 2,000

WEIGHT NECESSARY FOR COLLECTOR — ~.1 lb.

COST PER COLLECTOR	Desiccant Only
100	30 cents
1,000	10 cents
10,000	9.7 cents
50,000	7.1 cents

COMMENT: Hard form of silica gel has similar properties but is less likely to degrade than silica gel.

DESICCANT

TYPE	Linde Molecular Sieve Type 4A
SOURCE	Union Carbide, Linde Division, Molecular Sieve Department, Old Saw Mill River Road, Tarrytown, New York 10591, (914) 345-3460
CAPACITY	22% - weight of H_2O/100 lbs. of dry desiccant Our test showed sorption of 6.5% after 48 hours of outdoor exposure.
REGENERATION	Can be regenerated by purging or evacuating at elevated temperatures. The degree of regeneration is dependent on the temperature and humidity of the purge gas. Our test showed desorption of 9% after 6 hours at 130°F.
LIFE CYCLE	

CONTAINERS FOR PACKAGING

WEIGHT NECESSARY FOR COLLECTOR ~ .19 lb.

COST PER COLLECTOR

100	27 cents
1,000	27 cents
10,000	27 cents
50,000	27 cents

COMMENT: Requires greater regeneration temperature than silica gel.

APPENDIX L

DESICCANT SORPTION/DESORPTION CHARACTERISTICS

The use of an air-drying system in the collector is considered necessary in order to prevent moisture build-up and resultant condensation on the internal surface(s) of the glass cover(s). A completely passive system, such as a desiccant, also is desirable. Several commercial desiccants are available in various forms. Samples of four types were obtained for testing.

The basic requirements of moisture retention at temperatures close to ambient for later thermal cycling to drive off the moisture at collector operating temperatures is satisfied by most desiccants. The collector operation is such that during evening hours the relatively moist, cool air is drawn through the desiccant because of the collector design. Transmission through the desiccant dries the moisture-laden air, providing a dry environment for heat-up and air expulsion. A collector has a natural "breathing" action during the hot/cold cyclic operation. As the air within the collector heats up, the natural expansion pushes the dry, hot air through the desiccant to the outside environment. This expulsion of hot air causes the desiccant to give up the moisture it had absorbed during the cool period, thus regenerating the desiccant. At the end of the operating day when the collector cools off, the cycle begins again.

Three tests were felt to be necessary to provide the information required to determine which type dryer would be incorporated. They were: (1) sorption capability, (2) desorption capability, and (3) in-situ tests for compatibility requirements and actual operation.

Sorption Tests

Samples of the four desiccants - Linde's Synthetic Zeolite Molecular Sieve 4A (1/16-inch pellets), 8-mesh silica gel, 8-mesh Drierite®, and 4 x 8 mesh Natrasorb T® (a special type of silica gel) - were placed outdoors and weighed at intervals. Temperature and relative humidity were monitored during the tests.

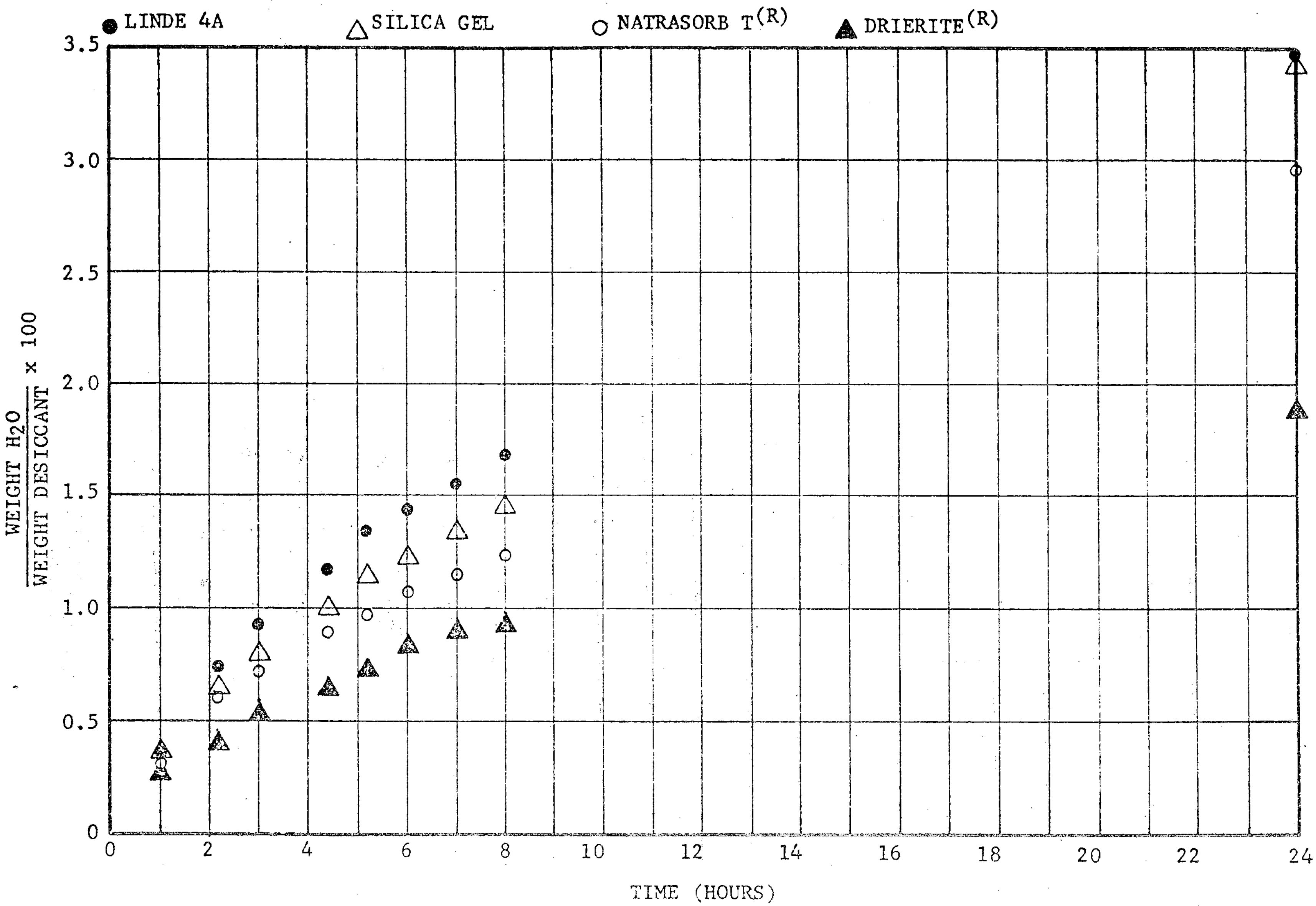
The test results are shown in Table L-1 and Figures L-1 and L-2.

TABLE L-1. RESULTS OF DESICCANT SORPTION TESTS

WEIGHT OF DESICCANT (IN GRAMS)			Linde	Silica Gel	Drierite(R)	Natrasorb T(R)
Weight of Beaker			7.25	7.22	7.25	7.50
Weight of Beaker & Desiccant			45.23	43.99	55.72	53.48
Weight of Desiccant			37.98	36.77	48.47	45.98
Hour	Temperature	Relative % Humidity				
0	56	70	45.23	43.99	55.72	53.48
1	63	52	45.37	44.12	55.84	53.62
2:15	68	38	45.51	44.23	55.93	53.75
3	70	32	45.58	44.29	55.98	53.81
4:30	71	30	45.68	44.36	56.04	53.88
5:15	73	28	45.73	44.41	56.08	53.92
6	75	26	45.77	44.44	56.12	53.96
7	75	25	45.82	44.48	56.16	54.00
8	76	25	45.87	44.52	56.18	54.04
24	61	62	46.55	45.26	56.64	54.83
25	70	25	46.61	45.34	56.68	54.92
26	85	26	46.67	45.42	56.72	55.02
27	60	85	46.72	45.51	56.76	55.11
28:30	65	73	46.78	45.61	56.80	55.22
30	64	80	46.85	45.71	56.85	55.33
31	64	80	46.89	45.78	56.88	55.41
48	60	90	47.71	47.52	57.47	57.38
at 48 Hours	$\frac{\text{Weight } H_2O}{\text{Weight Desiccant}} \times 100$		6.5	9.6	3.6	8.5

Graphs showing the $\frac{\text{Weight } H_2O}{\text{Weight Desiccant}} \times 100$ as a function of time accompany the report.

NOTE: 1 gram of H_2O vapor is approximately the amount of vapor in one cubic foot of 90° saturated air and two cubic feet of 68° saturated air.



OUTSIDE TEMPERATURE = 60-75°F
HUMIDITY = 40-25%

Figure L-1. Sorption Characteristics of Desiccant During First Day of Test

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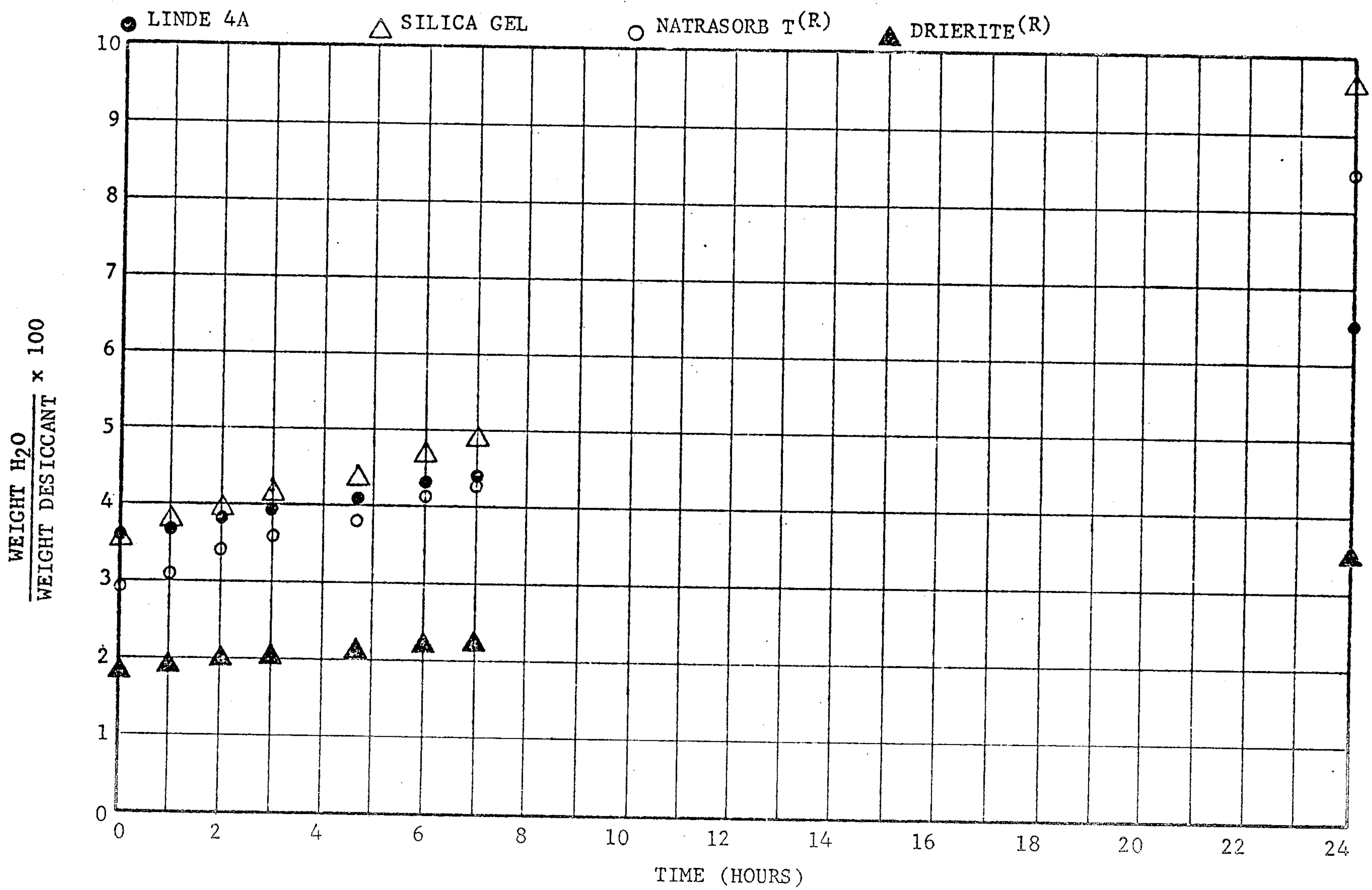

OUTSIDE TEMPERATURE = 60-64°F
HUMIDITY = 70-80%

Figure L-2. Sorption Characteristics of Desiccant During Second Day of Test

The silica gel products proved to be the best after two days exposure. However, after only one day of rather low humidity, the Linde Molecular Sieve was equal to the silica gel. This was to be expected since the Molecular Sieve 4A is promoted for its efficiency at low humidity. At high humidities, silica gel is more efficient and surpassed the capability of the 4A. Drierite® exhibited the poorest performance. Surprisingly, the capacities were not greater, but the desiccants are all adequate to dry the collector in volumes of less than 50 ml.

Desorption Tests

The same four candidate desiccants were tested to determine their desorption characteristics. The desiccants had been exposed to a relatively high humidity level environment for approximately one month and held a considerable amount of moisture.

Initially the four samples were weighed, then placed in an oven, operating at 130°F. The temperature was selected as a probable low value of collector operation. The samples were removed from the oven at intervals of one hour and weighed in order to determine the weight of moisture desorbed. The results are shown in Table L-2.

The silica gel is seen to desorb the highest rate at this relatively low temperature. The Drierite® performed better than had been anticipated, but in retrospect this could have been expected because Drierite® does hold some moisture by capillary action. It can be noted that most of the desorption in all samples occurred in the initial hour with the desorption rate decreasing rapidly. This is the type performance desired of the desiccant when in the collector.

This test and the previously discussed sorption test indicate that, of the desiccants tested, the silica gel material is superior in performance. It should be noted that there was no airflow through the desiccants during these tests as there will be in the collector. The results do provide the information that desorption and thus desiccant regeneration can take place

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TABLE L-2. DESORPTION CHARACTERISTICS OF DESICCANTS EXPOSED TO 130°F ENVIRONMENT

Desiccant	Linde	Silica Gel	Natrasorb T(R)	Drierite(R)
	Weight in Grams			
Weight of Dry Desiccant and Container	38.92	43.99	53.48	55.72
Weight of Wet Desiccant and Container				
At T = 0	45.08	54.67	66.32	59.11
= 1 hour	44.87	53.87	65.52	58.84
= 2 hours	44.76	53.45	65.23	58.72
= 3 hours	44.68	53.18	64.93	58.65
= 4 hours	44.60	52.90	64.62	58.60
= 5 hours	44.55	52.53	64.25	58.56
= 6 hours	44.52	52.22	64.02	58.55
Total Weight Loss	.56	2.45	2.30	.56
Loss as a Percent of Moisture Held	9%	23%	18%	16.5%

at temperatures which should be generated in the collector under normal operating temperatures.

In-Situ Tests

Previous testing, discussed above, showed that the silica gel product available from Davison Chemical was a good choice as a desiccant for the collector. It rated high as an adsorber of water vapor and was the best desorber at the operating temperature selected. In addition it can be purchased in a package design nicely suited for the intended purpose.

The in-situ tests were for the purpose of relating the previous results to the desiccant performance in actual solar collector operation.

A partially saturated air dryer was weighed and then placed in the test collector. After six days of collector operation (including two days under stagnation conditions), the canister was removed, weighed and placed back in the collector. This portion of the test was performed in the morning so that the desiccant would have adsorbed the moisture from the incoming air of the previous night. Two days later the dryer was again removed and weighed. This time the weighing was performed in the afternoon so that the desorption cycle would have been completed. The results are shown below.

Day	Weight in Grams
0	54.26
6 (Morning)	55.28
8 (Afternoon)	52.97

The test shows that moisture is being adsorbed during the cooling cycle and desorbed during the heat cycle. It also appears that the system is overpowered in the heat cycle so that more can be desorbed than is necessary and therefore the air dryer will not become moisture-saturated and thus exhausted.

There could be some error introduced by the necessity of opening the collector to remove the desiccant. This was done as quickly as possible by removing a portion of the foam insulation rather than removing the desiccant from the front of the collector. In addition, one cannot be certain if the moisture has been desorbed and exhausted from the collector or merely desorbed and still in the collector.

APPENDIX M

MISCELLANEOUS THERMAL PERFORMANCE TESTS

During the period of performance of Contract NAS8-31326, a parallel, Company-funded program was being conducted. The purpose of that development effort was to bring to the consumer market a solar collector which would be a viable, marketable subsystem from the standpoint of both performance/cost to the consumer and producibility with present Chamberlain capabilities. Many of the investigations which were undertaken during this time period had equal applicability to what is termed inhouse as the Chamberlain commercial collector and the NASA/MSFC collector. The two units are very similar with the exception of the method of attaching the cover plate(s). The miscellaneous thermal performance tests included in this appendix were obtained on 2 foot by 6 foot prototype units of the Chamberlain commercial collector where full-scale collectors were used. The tests were performed prior to prototype fabrication of the NASA/MSFC collector. Because of the similarity of the two units, extrapolation of these results to the NASA collector are possible. The tests described here are not inclusive of all tests conducted on the commercial prototype, but representative of results obtained.

Tests of Chamberlain Prototype with Black Chrome Absorber

The Chamberlain prototype collector is a 2 foot by 6 foot unit, using either one or two glass covers mounted in an aluminum extrusion similar to those manufactured by Chamberlain for insulating doors. The units employ roll-formed housings, foam insulation and desiccant systems very similar to the NASA/MSFC design. These prototypes used absorbers with parallel flow passages formed by seam-welding and hydraulic expansion. Both the Chamberlain full-scale collector (3 foot by 7 foot) and the NASA collector (3 foot by 8 foot) use the stitch-weld/hydraulically-formed absorber plate which eliminates finned areas on the plate.

The objective of these tests was to obtain performance data for the black chrome absorber plate when using a single ASG Water White cover. The absorber plate had been coated on both sides, so an effort was made to determine the effect of this low emittance coating on the back side of the

absorber as compared to the same system when painted with high temperature aluminum paint. The tests would allow an evaluation of the effectiveness of coating the back side from the cost standpoint. Normally, when the absorber plates are coated, they are placed in the plating tanks in pairs, mounted back-to-back to avoid coating the back surface. This absorber was not processed by that method, so the selective coating was applied to both surfaces.

The tests were conducted using three collectors: (1) the "control" collector which Chamberlain used for comparing results, (2) the collector with black chrome on both surfaces of the absorber, and (3) the collector with black chrome on the upper surface and bright aluminum paint on the back surface of the absorber plate.

The control collector (S/N 1001-1-A) was made up of the following components:

- 2 foot by 6 foot prototype collector box, Chamberlain Drawing No. J8077-21.

- Absorber plate: Chamberlain Drawing No. J8077-19-2; coating 3M Nextel® black paint, aluminum paint on back.

- Glazing: aluminum extruded frame, Drawing No. J8077-12, painted black with Duracron®, two covers, Libby-Owens-Ford 1/8-inch tempered glass. Composite transmissivity of 72.0 percent.

Test collector, S/N 1004, consisted of the following components:

- Collector box: same as control.

- Absorber plate coating: black chrome over satin nickel both sides, applied by Olympic Plating, Canton, Ohio.

- Glazing: aluminum extruded frame, Drawing No. J8077-13, painted black with Duracron®, single ASG Water White, 5/32-inch cover. Transmissivity 92.7 percent.

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Test collector, S/N 1005, was exactly the same as 1004 except the back of the absorber plate was painted with Aluminum Header Paint and baked at 250°F for 30 minutes.

Thermocouples were attached to the absorber plate, collector box and foam insulation as shown in Figure M-1.

The collectors were mounted on the test rack at an angle of 39° off the horizontal facing due south. The fluid used in both circuits was 50/50 by weight Prestone II antifreeze/water. Flow rate was 14.7 lbs/hr-ft^2 as recommended by NBS.

Five tests were conducted with S/N 1004 to obtain an approximate efficiency curve for the collector with a low emissivity coating on the back of the absorber plate. It was assumed that if the black chrome coating on the back of the absorber provided a significant increase in efficiency, the trend would show up even with this small number of tests. Also, only two of these tests were run concurrently with the control collector because the control circuit was being used for another test operation.

Fourteen tests were conducted with S/N 1005; all of which were run against the control. Tests were conducted at four inlet temperatures: 90°, 130°, 170° and 210°F. In all tests efficiency data were obtained only after the collector had reached stable conditions for approximately 15 minutes. Fluid inlet temperature did not vary more than ± .3°F during this period.

Instantaneous efficiency was calculated by observing average values of insolation and Δt over a two to five minute span at the end of this 15 minute period. Efficiency was calculated using the following formula:

$$\text{Efficiency} = \frac{\dot{m}\, C_p\, \Delta t}{I\, A}$$

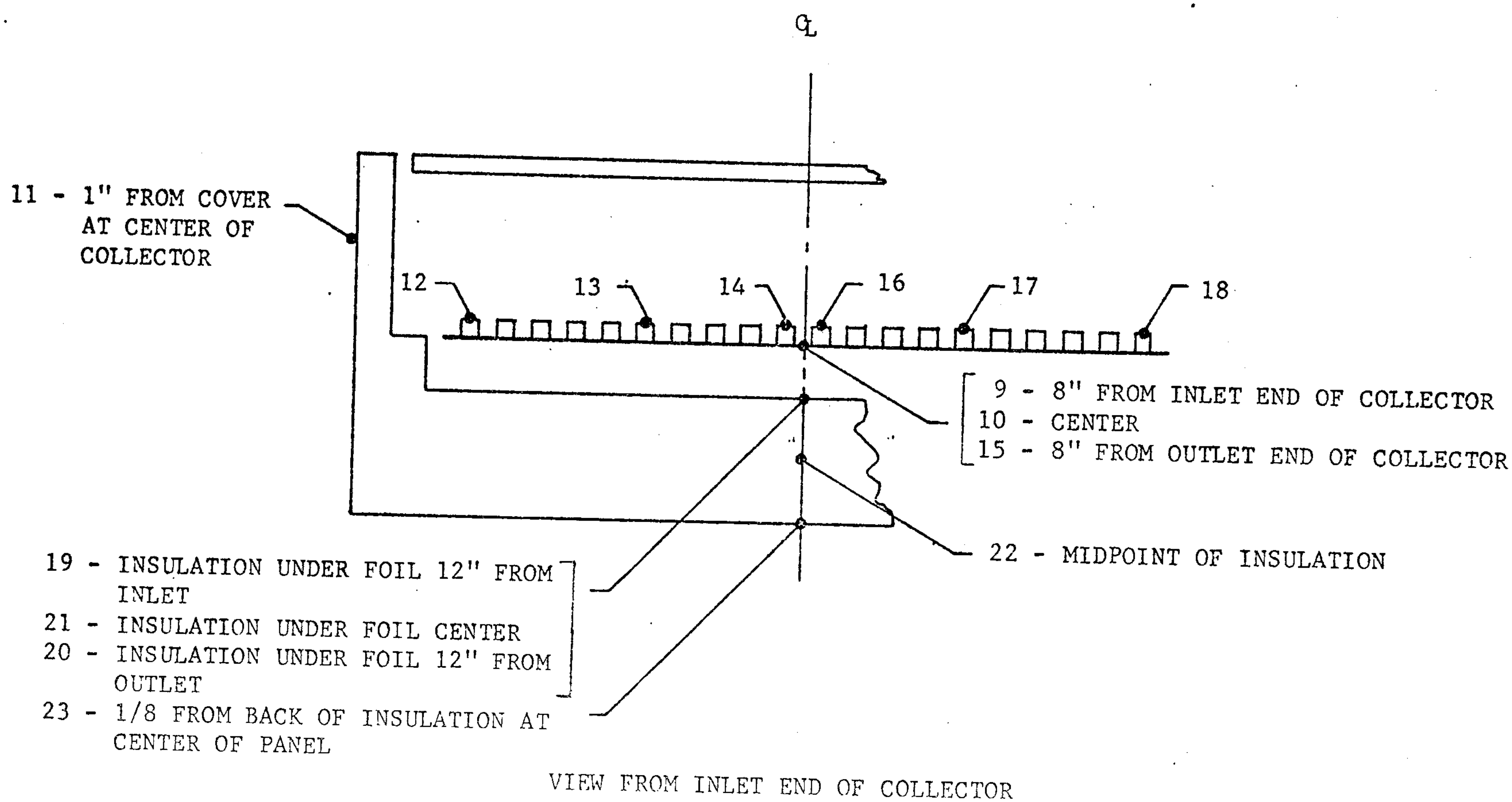

Figure M-1. Thermocouple Locations for Performance Tests on Collectors 1004 and 1005

where: $\dot{m}$ = 14.7 lbs/hr-ft^2

C_p = specific heat of fluid at the average fluid temperature in the collector

Δt = °F

I = insolation, BTU/hr-ft^2

A = gross area of the collector = 12 ft^2

The results indicate that the assumption of establishing a performance curve with a minimum of four datum points was not a good assumption. The efficiency versus $\Delta t/I$ curve shown in Figure M-2 shows both a lower ordinate intercept (0.689) and a higher loss coefficient (0.898) than that obtained on collector 1005 (0.752 and 0.872, respectively). Since the results on 1005 are determined with a much larger number of datum points, more confidence must be placed on these data. In addition, the datum points in Figure M-2 which are labeled 25 and 28 agree almost exactly with the results in Figure M-3, while those labeled 24 and 26 do not agree. The only conclusions which can be reached from these results is that the black chrome, single cover collector is a more efficient collector than the two cover, Nextel® unit. It cannot be stated categorically, but the results would indicate that there is probably very little, if any, to be gained by coating both sides of the absorber plate with black chrome, and certainly would not be cost effective. The losses indicated for the collector by Figure M-2 are probably in error due to the limited data available. Tabulated values of the test data are given in Table M-1.

The temperature distribution values for the above tests are provided in Table M-2. The datum points of most interest in these results would be the distribution through the foam insulation, points 21, 22 and 23, as shown in Figure M-1, and the distribution on the interior surface of the foam, points 19, 20 and 21. The foam operating temperature is of major concern because of the possibility of material degradation at high temperatures.

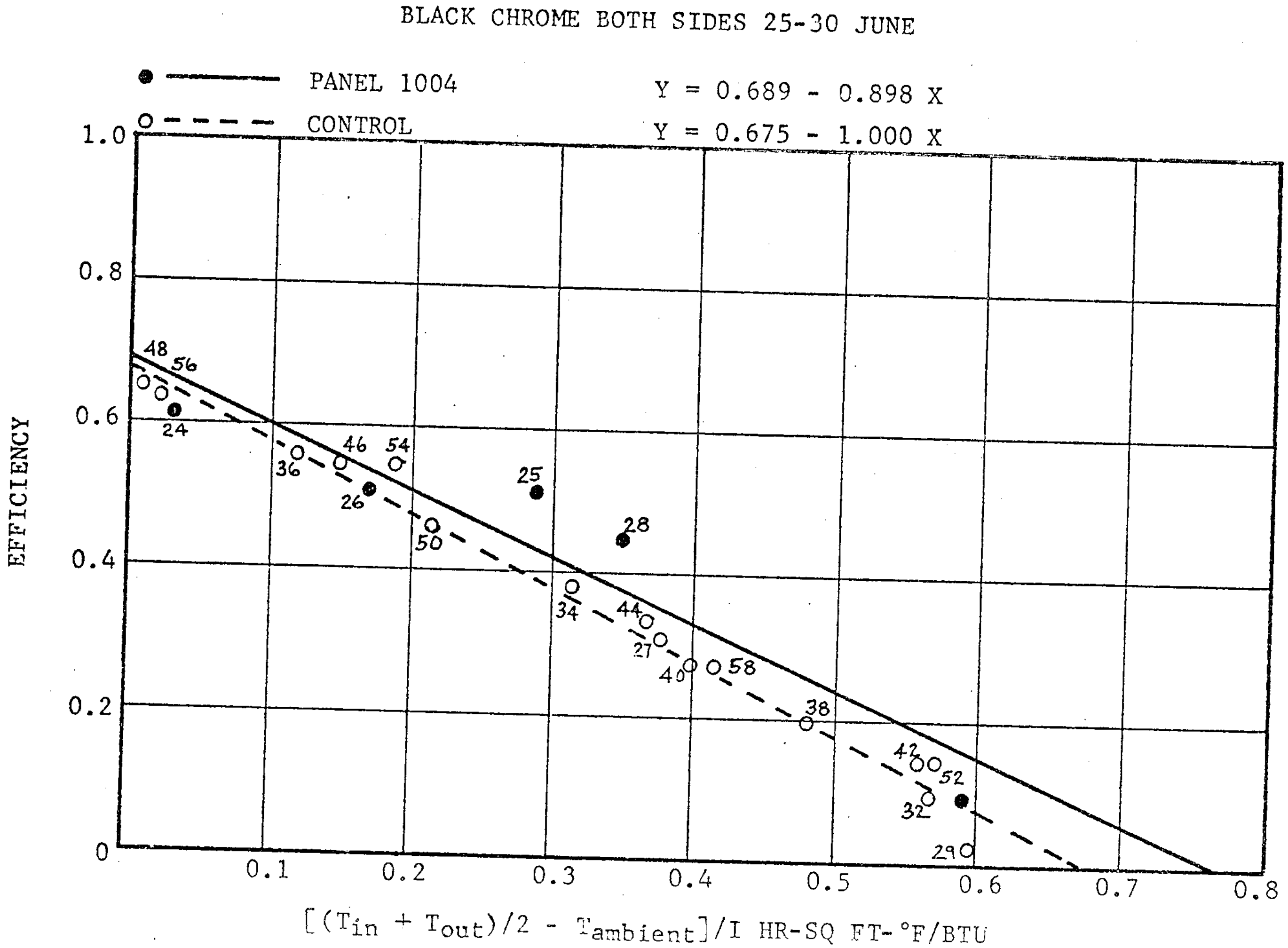

Figure M-2. Thermal Performance of Collector with Black Chrome Plating Both Sides Compared to Control Collector

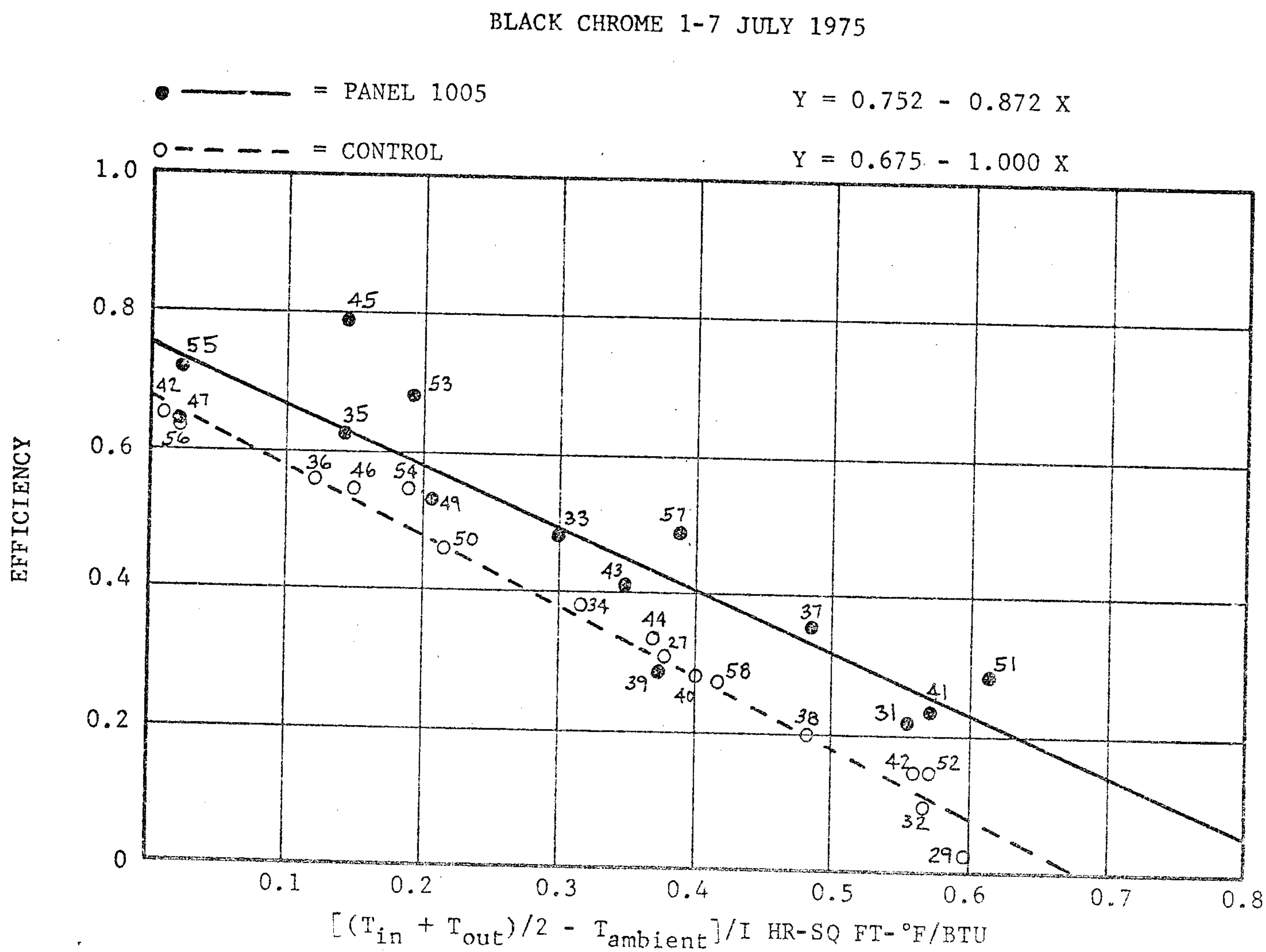

Figure M-3. Thermal Performance of Collector with Black Chrome/ Aluminum Paint Compared to Control Collector

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TABLE M-1. TEST DATA FOR COMPARING COLLECTOR PERFORMANCE FOR UNITS 1004, 1005 AND 1001-1-A (CONTROL)

TEST NO.	DATE	TIME CDT	S/N*	AMBIENT TEMP. (°F)	WIND (mph)	FLOW RATE GPM AT °F	INLET TEMP. (°F)	ΔT (°F)	INSOLATION (Langleys/ Minute)	EFFICIENCY (%)
X / 24	25 Jun 75	1440	X / 1004	90	10	.2735 at 71	X / 90	X / 15.3	1.135	X / 61.0
X / 25	27 Jun 75	1300	X / 1004	90	5	.277 at 96	X / 168	X / 14.35	1.342	X / 50.7
X / 26	27 Jun 75	1130	X / 1004	90	3	.277 at 96	X / 126	X / 12.39	1.133	X / 50.7
27 / 28	30 Jun 75	1342	Control / 1004	92	3	.276 at 96	184 / 175	7.17 / 10.65	1.146	29.8 / 44.2
29 / 30	30 Jun 75	1527	Control / 1004	92	5	.278 at 120	220 / 218	.37 / 1.83	.975	1.8 / 9.1
31 / 32	1 Jul 75	1100	1005 / Control	91	5	.2785 at 118	213 / 217	4.51 / 1.83	1.014	21.6 / 8.9
33 / 34	1 Jul 75	1317	1005 / Control	97	3	.276 at 75	175 / 181	12.83 / 9.96	1.28	47.9 / 37.1
35 / 36	1 Jul 75	1430	1005 / Control	97	8	.277 at 97	126 / 121	16.11 / 14.25	1.20	62.3 / 54.8
37 / 38	2 Jul 75	1430	1005 / Control	95	8	.2785 at 120	209 / 210	8.00 / 4.30	1.104	35.2 / 18.9
39 / 40	2 Jul 75	1525	1005 / Control	94	8	.276 at 96	176 / 182	6.22 / 5.73	1.035	28.8 / 26.4
41 / 42	3 Jul 75	1100	1005 / Control	89	9	.278 at 120	213 / 211	4.75 / 2.85	1.001	23.1 / 13.9
43 / 44	3 Jul 75	1215	1005 / Control	92	5	.276 at 92	176 / 182	9.93 / 7.90	1.058	40.8 / 32.6
45 / 46	3 Jul 75	1310	1005 / Control	93	9	.276 at 99	121 / 126	20.60 / 14.02	1.214	78.6 / 53.5
47 / 48	3 Jul 75	1408	1005 / Control	95	6	.271 at 72	92 / 89	16.60 / 16.67	1.178	64.1 / 64.2
49 / 50	3 Jul 75	1520	1005 / Control	92	4	.277 at 105	133 / 136	11.84 / 10.08	1.040	53.0 / 45.2
51 / 52	7 Jul 75	1045	1005 / Control	84	3	.278 at 115	216 / 208	5.79 / 2.81	.996	28.3 / 13.7
53 / 54	7 Jul 75	1335	1005 / Control	88	3	.277 at 105	133 / 134	18.77 / 14.83	1.288	67.9 / 53.6
55 / 56	7 Jul 75	1430	1005 / Control	94	2	.274 at 72	90 / 91	22.14 / 19.38	1.404	71.6 / 62.7
57 / 58	7 Jul 75	1550	1005 / Control	90	4	.276 at 92	172 / 181	10.42 / 5.65	1.022	48.4 / 26.2

* 1004 - Black chrome both sides absorber plate
1005 - Black chrome front, aluminum paint back
Control - Control collector
X - No control collector tested

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TABLE M-2. TEMPERATURE VALUES AT LOCATIONS WITHIN COLLECTORS 1004 AND 1005 DURING PERFORMANCE TESTING

TEST NO.	28	30	31	33	35	37	39	41	43	45	47	49	51	53	55	57
CHANNEL	S/N 1004	S/N 1004	S/N 1005	S/N 1005	S/N 1005	S/N 1005	S/N 1005	S/N 1005	S/N 1005	S/N 1005	S/N 1005	S/N 1005	S/N 1005	S/N 1005	S/N 1005	S/N 1005
9	-	218	215	180	133	214	178	215	180	133	97	138	219	142	100	178
10	-	219	217	184	138	216	182	215	182	138	103	142	218	146	106	179
11	110	120	104	114	125	113	112	102	104	104	108	113	108	108	115	116
12*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	189	221	219	189	144	220	185	220	188	144	110	147	223	154	114	182
14	189	220	218	188	143	218	184	218	187	143	109	146	222	152	113	182
15	189	220	218	188	143	218	184	218	187	143	109	146	222	152	113	182
16	189	221	218	187	142	218	184	218	186	142	108	146	222	152	112	182
17	188	220	218	187	143	218	184	218	187	143	110	146	222	153	114	182
18	188	217	211	188	148	217	185	211	186	146	116	150	213	156	122	183
19	133	151	150	136	114	154	137	153	138	115	97	116	153	118	97	134
20	144	161	160	147	123	166	145	160	145	122	105	122	160	125	105	140
21	-	148	149	139	119	156	140	153	139	118	103	117	152	120	102	134
22	103	108	106	110	104	113	108	108	96	102	99	102	106	101	97	104
23	92	92	90	97	97	96	94	89	92	93	95	92	84	88	94	90
Ambient	92	92	89	97	97	96	94	89	92	93	95	92	84	88	94	90
Inlet Temp.	175	218	213	175	127	209	176	213	176	121	92	133	216	133	90	172
Time	1345	1535	1100	1317	1430	1435	1520	1100	1215	1310	1410	1515	1045	1340	1435	1550
Insolation	1.146	.975	1.014	1.28	1.20	1.104	1.035	1.001	1.158	1.214	1.178	1.040	.996	1.288	1.404	1.022

* Bad Thermocouple

The temperatures when operating the collector with an inlet temperature of 218°F are shown for test number 30. This was the highest value run. The distribution through the foam (21, 22, 23) shows that the major portion of the temperature drop occurs through the first inch of foam (from the inside surface), showing a 40° Δt. The second inch shows a 16° Δt. The inside surface of the foam is operating approximately 70°F cooler than the absorber plate. Later tests (stagnation) will show that this Δt increases greatly with operating temperature. Thermocouples 13-18 (12 was inoperative) provide the absorber plate temperature distribution, and it is seen that the flow through the panel is extremely uniform.

Prototype Collector Stagnation Tests

A stagnation test was conducted on the 2 foot by 6 foot prototype collector with a black chrome absorber surface and double ASG glass cover. Physical measurements were taken to determine expansion of the collector and thermocouple data were recorded to obtain maximum temperatures at various points on the collector under stagnation conditions.

The objectives of the test were as follows:

1. Observe the expansion characteristics of the foam insulation under stagnation conditions. Determine if the insulation expands a substantial amount and if so where at.

2. Determine what temperature the insulation directly under the foil will attain under stagnation conditions.

3. Determine the temperature gradient through the thickness of the insulation on the back of the collector and also the temperature on the side of the collector box.

4. Determine the stagnation temperature of the absorber plate.

5. Provide additional temperature data for the stagnation environment.

Thermocouples were placed on the collector box, absorber plate, and glass cover as shown in Figure M-4. The following components were used to make up the collector.

- 2 foot by 6 foot prototype collector box, Chamberlain Drawing No. J8077-21, S/N 1003
- Absorber Plate, J8077-19-D, black chrome, no paint on back.
- Glazing: aluminum extruded frame, Chamberlain Drawing No. J8077-6, painted black, double glass 5/32-inch ASG Water White.

The width was measured at 12 inches from the inlet end, the center, and 12 inches from the outlet end immediately before testing. Dial indicators, mounted on a bracket, were set up to indicate any movement of the insulation toward or away from the absorber plate and also to show any change in thickness of the back insulation. These measurements were taken 30 inches from the outlet end of the collector box and 12 inches from either side. The collector was mounted at 39° off horizontal facing due south.

The following equipment was used in addition to the standard lab monitoring instrumentation:

- Two dial indicators, .001 graduation, were used to monitor thickness of the back insulation and also any movement toward or away from the absorber plate. This was done by drilling a 1/4-inch diameter hole through the back of the insulation and attaching a dial indicator to a 2 inch by 2 inch plate on the foil on the inside surface of the insulation. The other dial indicator was placed against a two-inch square plate on the outside surface of the insulation one inch to the side of the inside indicator.
- A 26-inch Vernier Caliper (.001 graduations) was used to measure the width of the collector before the test and at stagnation temperature.

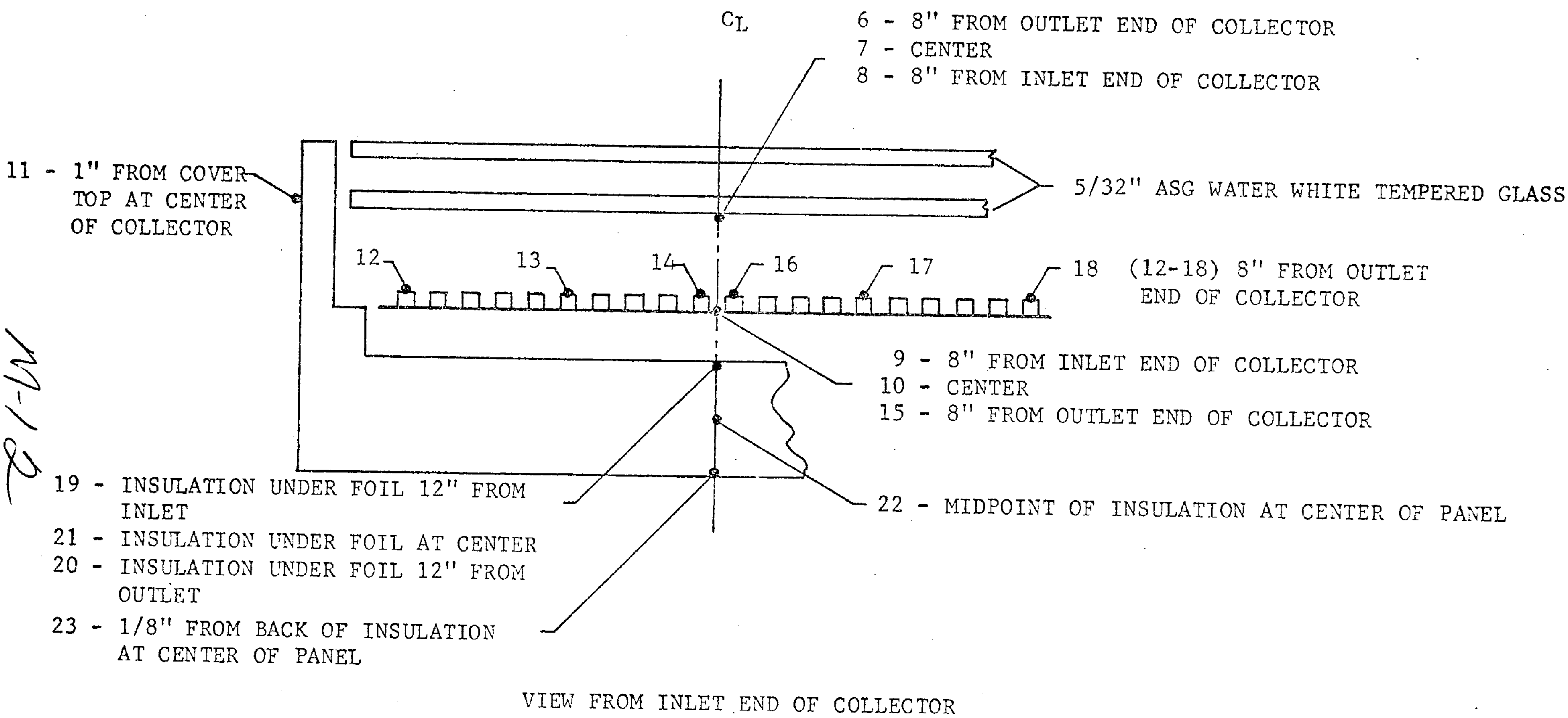


Figure M-4. Thermocouple Location for Stagnation Test

Thermocouple data are summarized in Table M-3. Reference Figure M-4 for the location of the thermocouple positions 6 through 23 called out in Table M-3.

TABLE M-3. STAGNATION TEST THERMOCOUPLE DATA

POSITION	TEMPERATURE °F
6	200
7	217
8	177
9	289
10	302
11	100
12	309
13	314
14	306
15	305
16	304
17	298
18	280
19	162
20	182
21	182
22	106
23	72
Ambient	70

The thickness and movement of the back insulation in relation to the absorber plate is given below. The thickness of the insulation increased only .006 maximum. The insulation was found to warp away from the absorber plate, not toward it, as collector temperatures rise.

TIME (CDT)	SURFACE MOVEMENT *		CHANGE IN THICKNESS
	INSIDE	OUTSIDE	
1115	.000	-.005	+.005
1130	-.010	-.010	0
1155	-.014	-.017	+.003
1245	-.028	-.032	+.004
1330	-.038	-.043	+.005
1345	-.041	-.046	+.005
1420	-.042	-.048	+.006
1450	-.040	-.045	+.005
1515	-.041	-.045	+.004

* + indicates movement toward the absorber plate.

The change in width of the collector was found to be a maximum of .064 inch. Data are shown below:

TIME (CDT)	WIDTH (INCHES) AT		
	OUTLET	CENTER	INLET
800	23.842	23.886	23.850
1400	23.904	23.950	23.908

The temperature of the insulation peaked at 1330 CDT and was found to be 182°F at positions 20 and 21 as given in Figure M-4. The thermocouple positions were directly under the foil at the center of the collector and at the top center. Bottom center (position 19) was 162°F.

The temperature gradient through the insulation was measured at the center of the panel and was found to be 182°F at foil, 106° at the midpoint, and 72° (2° over ambient) 1/8 inch away from the back surface (positions 21, 22, 23, respectively in Figure M-4). The temperature on the side of the collector box (position 11) was 100°F at stagnation.

Stagnation temperatures taken on the absorber plate measured on a line 6 inches from the outlet end of the plate across the entire width. From left to right these positions are 12, 13, 14, 15, 16, 17 and 18. Exact locations are given in Figure M-4. Stagnation temperatures at 1330 CDT at these points were respectively 309°, 314°, 306°, 305°, 304°, 298° and 280°. It is not known why position 18 was substantially lower than the others. Temperatures recorded at the center of the plate and at the inlet end center (positions 10 and 9) were 302° and 289°, respectively.

Temperatures on the inside surface of the inside glass were recorded at three positions (6, 7, 8 in Figure M-4). They were on the center of the glass width 8 inches from the outlet end, center of the glass and 8 inches from the inlet end. These temperatures were 200°, 217° and 177°, respectively.

Glass Temperature Distribution During Testing

Because of published information and private communications relating to the possibility of glass breakage caused by thermal effects, tests were conducted to determine what the temperature of the interior glass of a two-cover collector would be during normal operation.

A Chamberlain prototype collector, using two covers of Fourco glass (1/8 inch) and 3M Nextel® painted absorber plate were used. The Nextel® painted absorber plate was used because of the high emissivity factor. The radiation effects would be more severe during normal operation using the black paint than would be the case using black chrome.

Thermocouples were placed on the inside surface of the glass and on the absorber plate as shown on the accompanying figure (M-5). The tests were conducted during normal efficiency tests. The data were recorded on the solar laboratory strip chart recorder, then fit with a least squares form. The results are given in Table M-4 and Figure M-6.

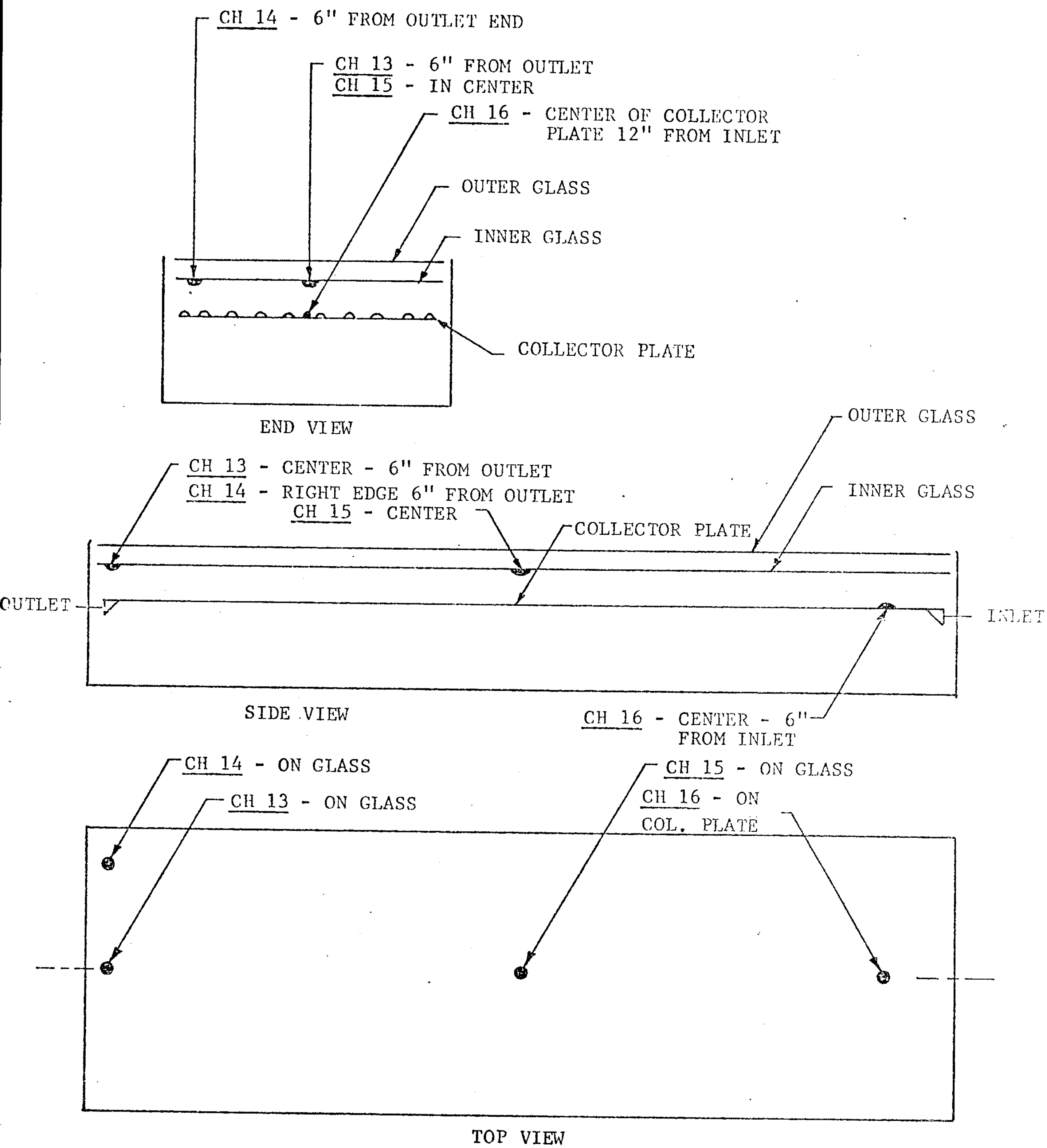
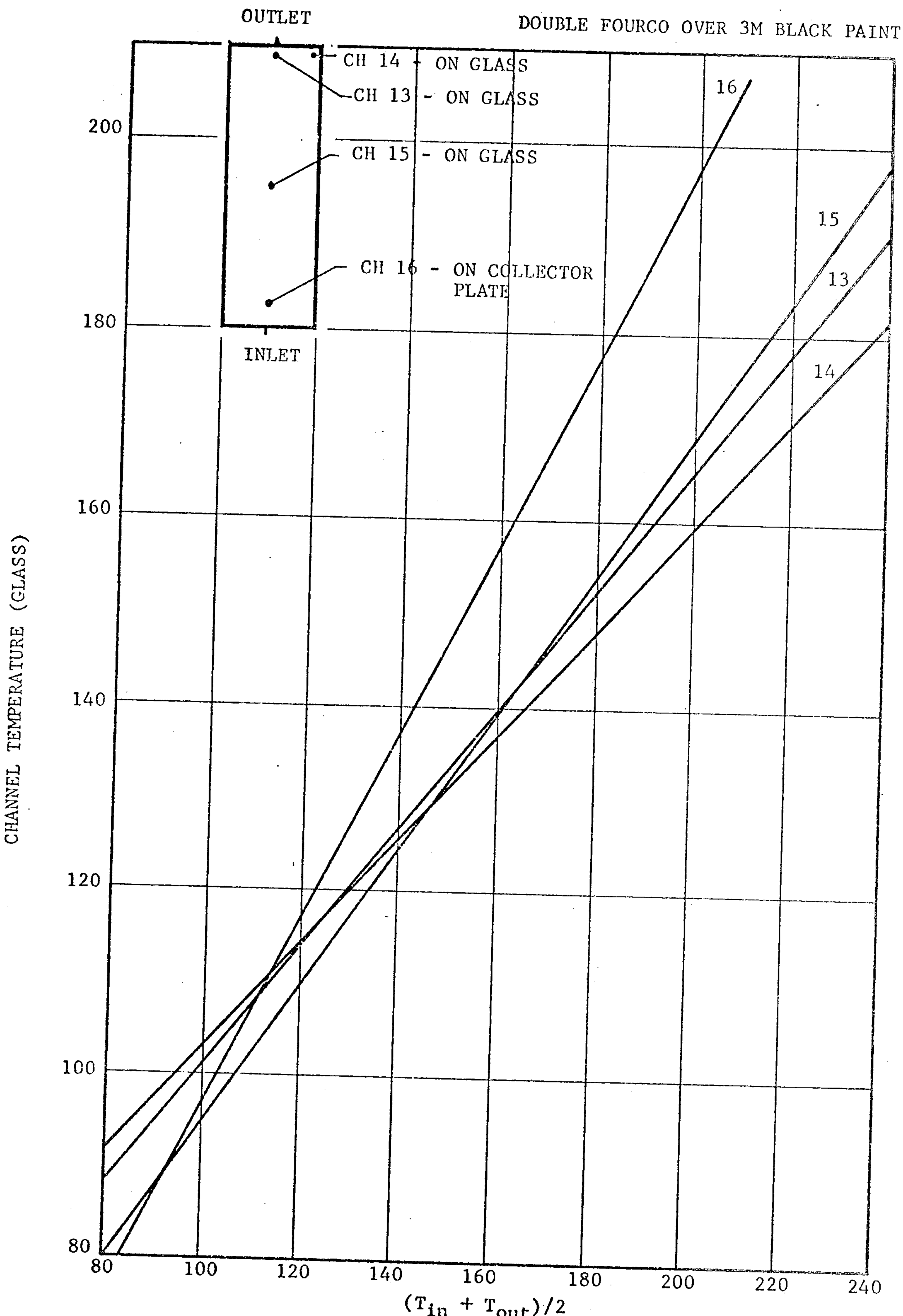


Figure M-5. Placement of Thermocouples

TABLE M-4. RESULTS OF GLASS TEMPERATURE DISTRIBUTION UNDER NORMAL OPERATING CONDITIONS

DATE	T_i	T_o	$(T_i + T_o)/2$	I	CHANNEL NO. 13	14	15*	16	WIND	TIME	T_a
2 Oct 75	187.8	194.6	191.2	1.2	159	155	161	188	--	2:32 CDT	56
2 Oct 75	163.2	169.1	166.2	.96	140	137	141	163	S at 5 mph	3:[illegible] CDT	57
3 Oct 75	110.2	122.6	116.4	1.07	108	106	106	113	S at 12 mph	11:[illegible] CDT	52
3 Oct 75	154.9	166.4	160.65	1.26	140	136	140	157	S at 15 mph	12:41 CDT	60
6 Oct 75	194.8	201.7	198.25	1.198	172.5	168	172	195	S at 1-2 mph	2:14 CDT	74
6 Oct 75	138.3	146.5	142.4	.964	131	132	128	140	--	3:[illegible] CDT	76
10 Oct 75	195.5	196.3	195.9	.93	154	145	163	194	NW at 8 mph	10:[illegible] CDT	48
10 Oct 75	167.4	177.1	172.25	1.15	149	144	148	169	W at 5 mph	12:[illegible] CDT	55
10 Oct 75	130.9	140.8	135.85	1.10	123.5	123.5	121	133	--	--	60
21 Oct 75	131.1	141.6	136.35	1.01	129.5	129	123.5	133	--	2:[illegible] CDT	70

* The collector plate was only about 0.5 inch from No. 15 (on the glass) due to warping of the plate.



M-18

Figure M-6. Glass Temperature as a Function of Average Fluid Temperature

The plotted data show that there are relatively significant differences in glass temperatures at the low and high temperatures, but in the mid-range there is basically no differences with respect to location on the glass. The wide variation in ambient temperatures and wind speed could have some effect on these results, but the use of two covers should minimize these parameters' effect on the temperature. The glass manufacturer was contacted in regard to these results. Chamberlain was advised that the limited results obtained here would indicate that no problems with glass breakage should exist, provided that there was sufficient expansion volume in the glazing channel to account for the glass expansion. No glass breakage in the prototype units had been experienced at the time of these tests, even though units had been undergoing tests for several months.

Small Scale Stagnation Tests

A series of sub-scale tests were conducted to determine the effect of materials and coatings on the temperature attainable under stagnation conditions. All the tests were conducted using identical, 12-inch square housings, constructed as shown in Figure M-7. Ten assemblies were fabricated and tested.

The stagnation temperature of each box was measured with a copper-constantan thermocouple. The thermocouple was held, with adhesive, to the back (dark) side of the absorber plate and positioned near its center with a small quantity of silicone rubber gum. The assembled units were positioned facing the south at an inclination of 39° from horizontal. Temperatures from the tests were recorded on a chart which then were analyzed. Stagnation temperatures to be used for analyzing were taken after the temperature of all units had stabilized.

A test also was conducted to determine if all units being tested had equal heat loss and would therefore cool off at the same rate. The test was conducted by simply placing a flat aluminum shield over the glass to prevent the sun's rays from striking the assembly surface. The thermocouple recorder chart then was analyzed to determine if all temperature plots decreased in a similar manner.

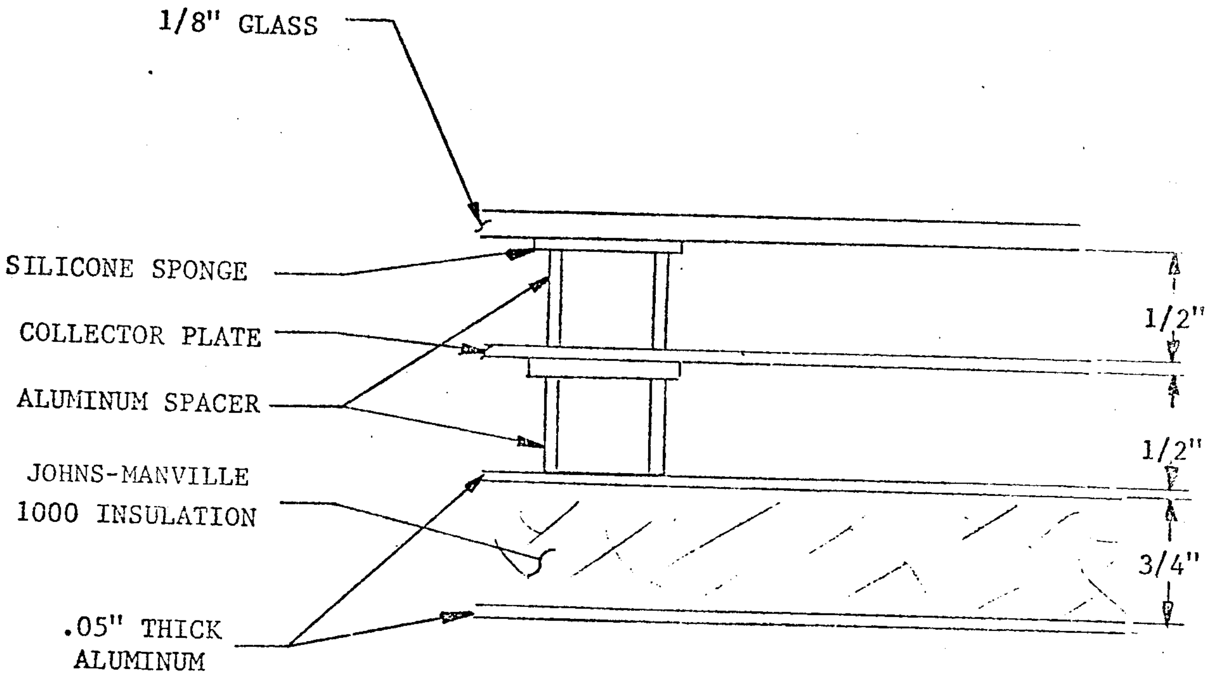


Figure M-7. Cross-Section of Sub-Scale Stagnation Boxes

Further, a test was conducted to determine if a uniform heat-up cycle would occur, or if some absorber plates would heat up faster or slower than the others. This test was conducted by covering the units until ambient temperature was reached. The units then were uncovered simultaneously, with the temperatures being recorded on a chart for later reading.

Absorber plate material, material thickness, material preparation, and absorber plate coatings were all variables. Table M-5 is a listing of each absorber plate.

Several collectors were fabricated in duplicate to confirm temperature accuracy. These collectors included Nos. 9000-1A, 1B and 1C, which had a mild steel absorber plate coated with 3M Nextel® paint; 9001-1A and 1B which used an etched aluminum plate coated with 3M Nextel® paint; and units numbered 9003-1A and 1B, which had a black copper over copper coating on mild steel.

As shown on the accompanying table (M-6) the black copper on copper selective surface placed on a mild steel collector plate had the highest stagnation temperature. The order of performance was as follows with the highest stagnation temperature unit being listed first:

1. Black copper on copper on .05 inch thick mild steel.
2. Caldwell Black Stove Paint (95% and 87%) on .03 inch mild steel.
3. Iron Oxide on .03 inch thick mild steel.
4. 3M's black Nextel® paint on .05 inch thick mild steel.
5. 3M's black Nextel® paint on .05 inch thick aluminum.
6. 3M's black Nextel® paint on .05 inch thick etched aluminum.

The following table (M-6) shows the average temperature of each type of absorber plate using the lowest temperature absorber plate as the base temperature.

TABLE M-5. ABSORBER PLATE DESCRIPTIONS

ABSORBER ASSEMBLY NO.	ABSORBER PLATE NO.	ABSORBER PLATE DESCRIPTION
9000-1A	911-1A	3M's[1] Nextel(R) black paint applied to .05 inch thick steel with the back of the plate being painted silver.
9000-1B	911-1B	Same as 9000-1A.
9000-1C	911-1C	Same as 9000-1A.
9001-1A	912-1A	3M's[1] Nextel(R) black paint applied to .05 inch thick surface etched aluminum with the back side of the plate being painted silver.
9001-1B	912-1B	Same as 9001-1A.
9002-1A	913-1A	3M's[1] Nextel(R) black paint applied to .05 inch thick aluminum with the back side of the plate being painted silver.
9003-1A[2]	902-1C	Black copper over copper applied to .050 thick mild steel. Coating was applied to both sides of plate.
9003-1B	902-	Same as 9003-1A.
9004-1A[2]	901-1A	Iron oxide applied to .05 inch thick mild steel. Coating was applied to both sides of plate.
9005-1A[3]	914-1A	Caldwell black stove paint (.95 absorptivity, .87 emittance) applied to .03 inch thick mild steel. Coating was applied to both sides of the plate.

NOTES: 1. Decorative Products Division 3M, 3M Center, St. Paul, Minnesota 55101

2. Enthone Corporation, New Haven, Connecticut.

3. Caldwell Chemical Coatings, Fayetteville, Tennessee.

TABLE M-6. ABSORBER PLATE PERFORMANCE

AVERAGE TEMP. OF ALL TESTS	TEMP. (°F) ABOVE COOLEST ABSORBER PLATE	ABSORBER I.D. NO.	BRIEF DESCRIPTION
209°F	29°F	9003-1A	Black Copper on Copper
200°F	20°F	9005-1A	Stove Black Paint
194°F	14°F	9004-1A	Iron Oxide
188°F	8°F	9000-1A	3M Nextel® Paint on Mild Steel
185°F	5°F	9002-1A	3M Nextel® Paint on Aluminum
180°F	0	9001-1A	3M Nextel® Paint on Etched Aluminum

Results from the heat loss test showed that all of the units cooled off at a uniform rate.

The test to determine if the heat-up process would occur uniformly with all the absorber plate types indicated that uniform heating of the units did occur with no single unit heating up faster than the others. These tests also demonstrated that the stagnation temperature was achieved after about 15 minutes of exposure to the sun.

The test was conducted on 7 June 1975. Maximum temperatures were obtained at 1330 CDT. There were very lightly scattered clouds in the morning until 1100 CDT and it was then perfectly clear through the test period 1515 CDT. Insolation was 243 BTU/hr-ft^2 at 1100 hours and steadily increased to 276 at 1310 (solar noon). Integrated insolation from 1100 to 1330 was 637 BTU/ft^2 and average insolation for that period was 255 BTU/hr-ft^2. Ambient temperature was 70° from noon through 1400 CDT. Wind speed was recorded at 3-6 mph.

APPENDIX N

COLLECTOR DRAWINGS

NUT - JIC 37° FLARED TUBE FITTING

WEATHERHEAD C35105 X 8 (FOR 1/2-INCH O.D. TUBING)

MATERIAL: STEEL

UNLESS OTHERWISE SPECIFIED LIMITS ARE	
FRAC.	
.000	
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NAME

FLARE NUT

MATERIAL

CHAMBERLAIN MANUFACTURING Corporation
WATERLOO, IOWA

		DATES
DRAWN		
CHECKED	TES	5 SEPT 75
APPROVED		

SCALE

DATE OF PRINT

DESTROY PREVIOUS ISSUES

J8092-15

SLEEVE - JIC 37° FLARE TUBE FITTING

WEATHERHEAD - C35165 X 8 (FOR 5/8-INCH O.D. TUBING)

MATERIAL: STEEL

UNLESS OTHERWISE SPECIFIED LIMITS ARE		NAME: SLEEVE	DRAWN	DATES
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.000		MATERIAL	APPROVED	
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ALUMINUM FOIL, REFLECTIVE, 1-INCH WIDE

BY 264 LONG .003 THICK

UNLESS OTHERWISE SPECIFIED LIMITS ARE		NAME FACING, ALUMINUM	DRAWN	DATES
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"POP" RIVET
NO. AD42H
MATERIAL - ALUMINUM
STYLE HEAD - DOME HEAD
RIVET DIAMETER 1/8
MAXIMUM GRIP .063 - .125
MANDREL MATERIAL: STEEL
CORE DESIGN: HOLLOW CORE
(HOLE SIZE .129-.133)
(MAXIMUM LENGTH UNDER HEAD .316)

BY USM CORP.
"POP" RIVET DIVISION
OR EQUIV.

UNLESS OTHERWISE SPECIFIED LIMITS ARE		NAME: CLOSED END POP RIVET	DRAWN	DATES
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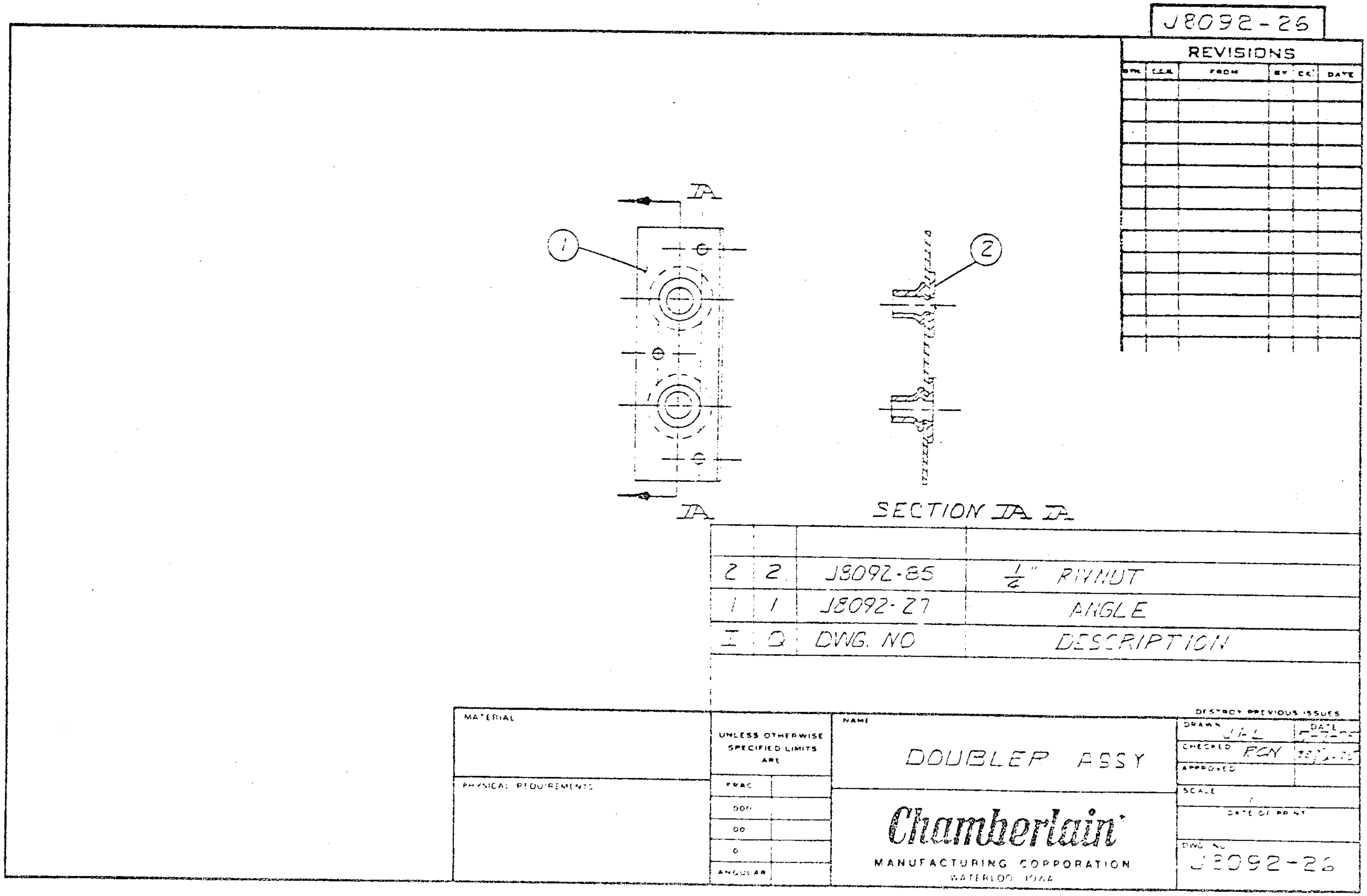
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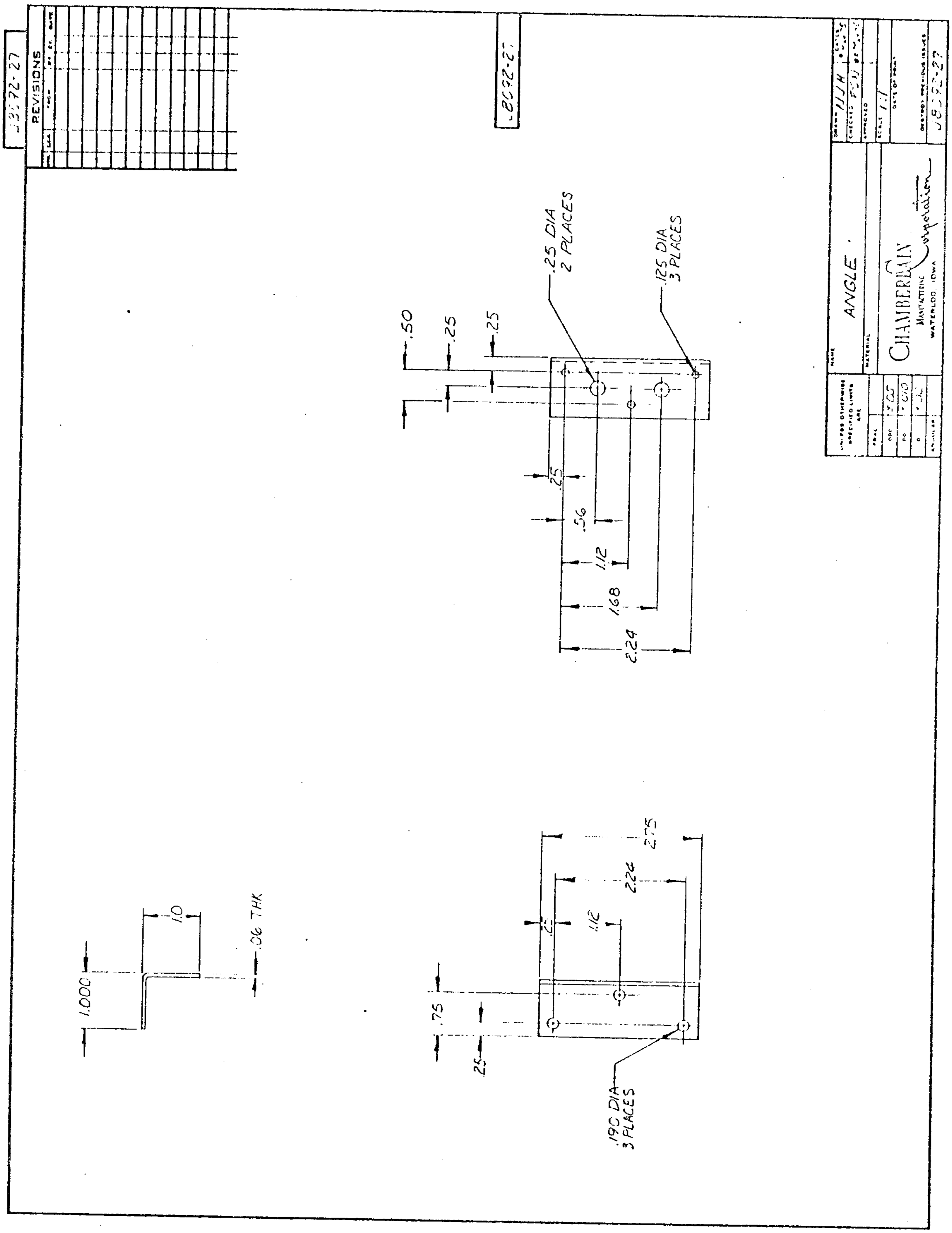

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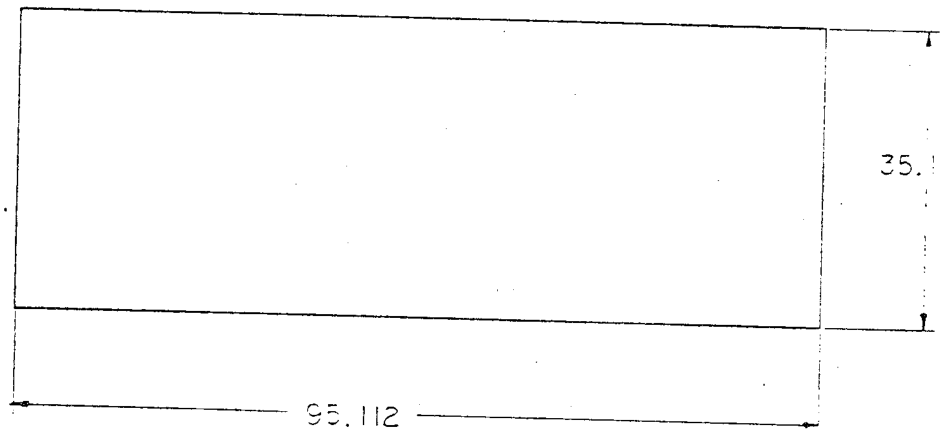

NOTE :
1. 3/16" FOURCO CLEARTEMP, EDGED.

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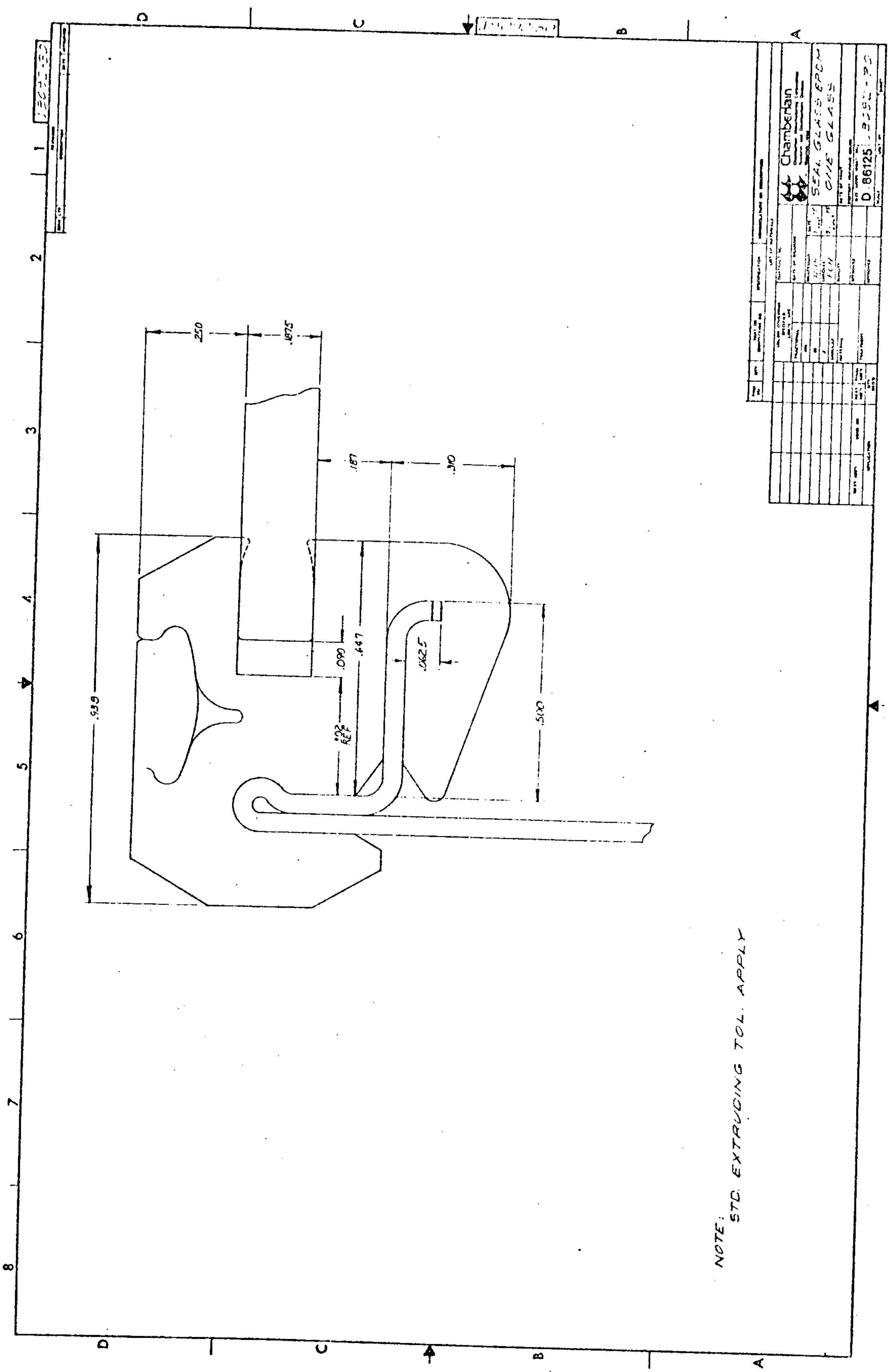
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Chamberlain
SEAL GLASS EPDM ONE GLASS
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SHEET ALUMINUM .003 INCH THICK x 95 INCHES x 35 INCHES

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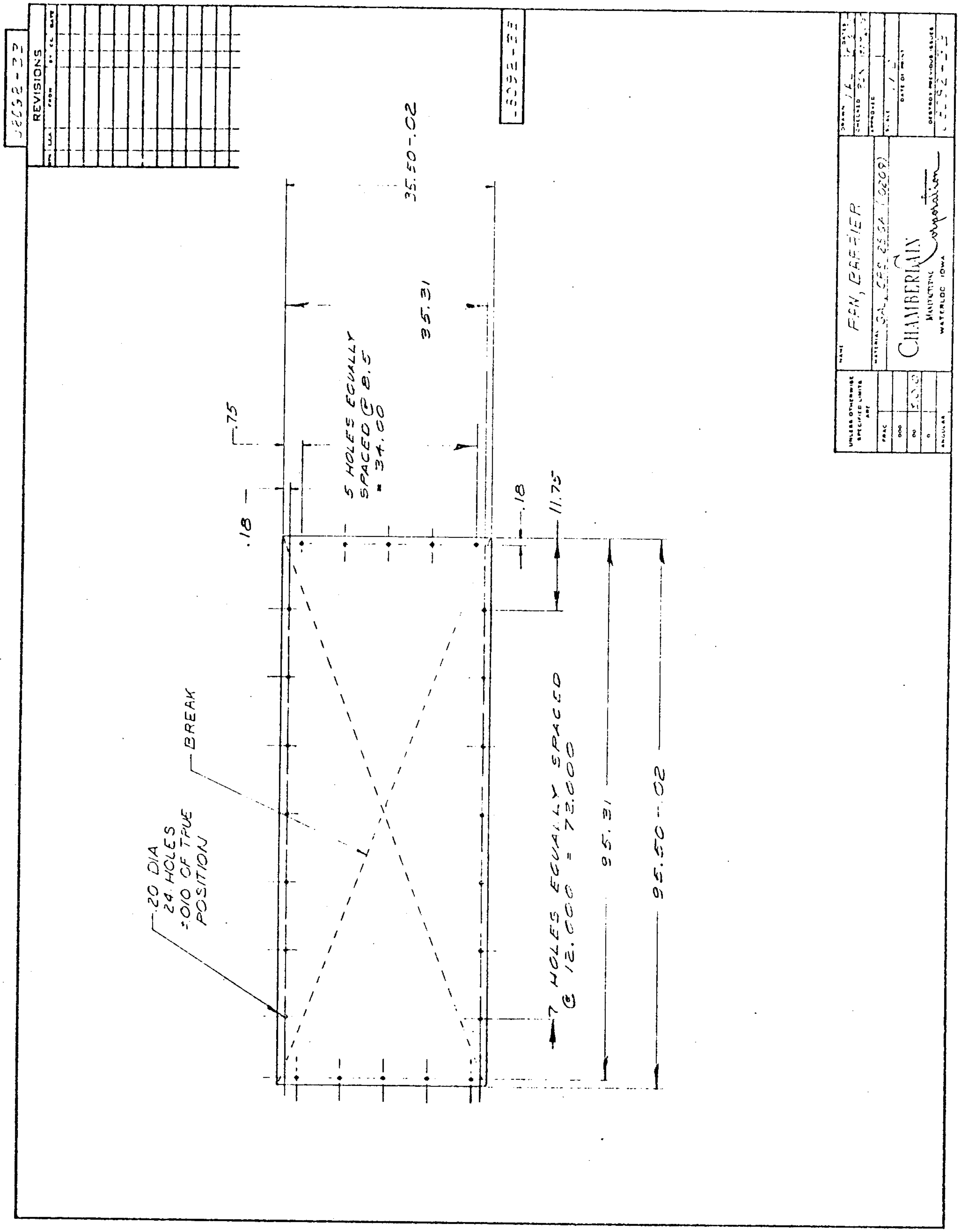

3M SEALER XA 5354 (ROLLED EXTRUDED BEAD)

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WITCO CHEMICAL ISOFOAM RC-3
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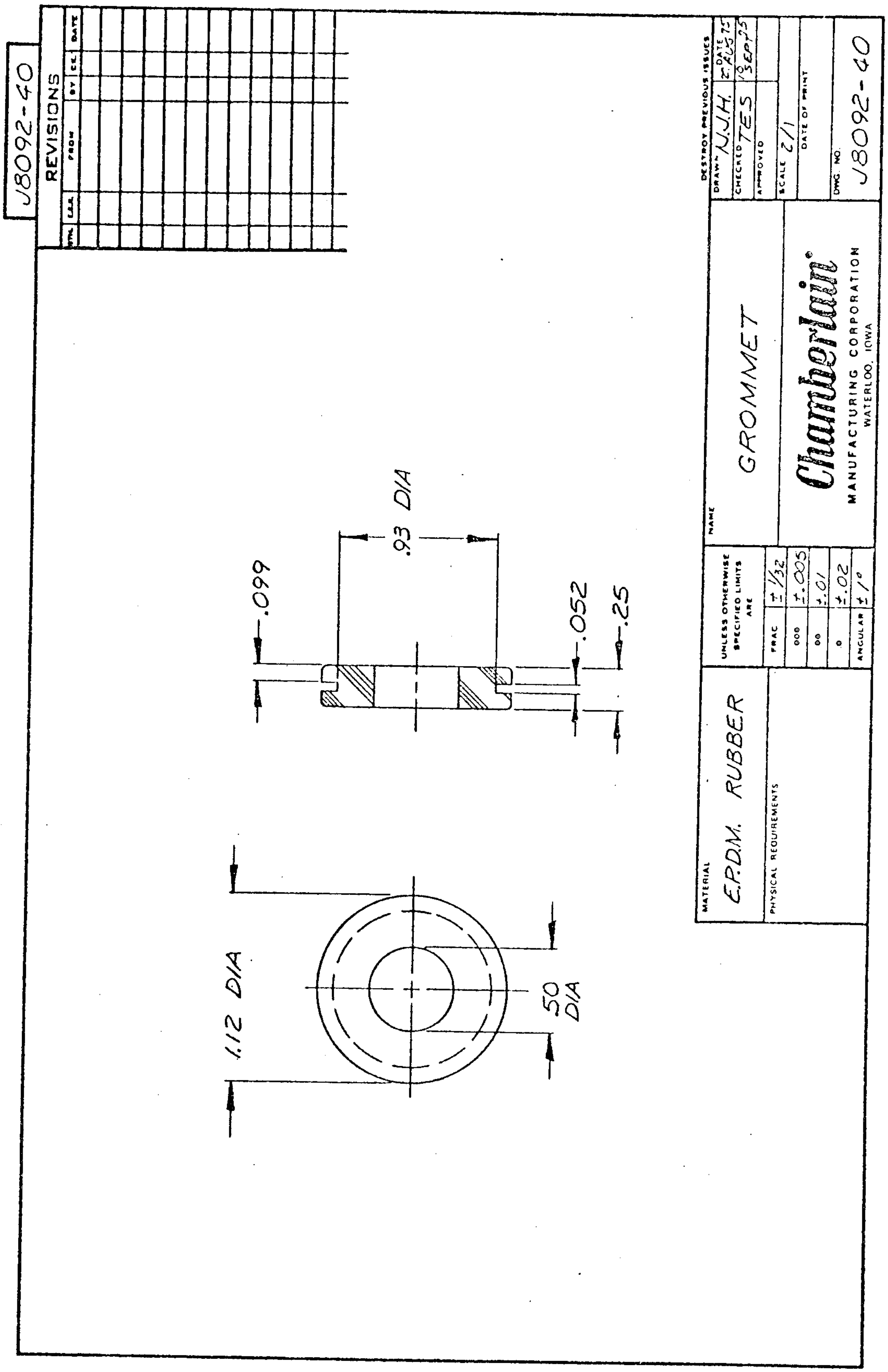
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WATERLOO, IOWA
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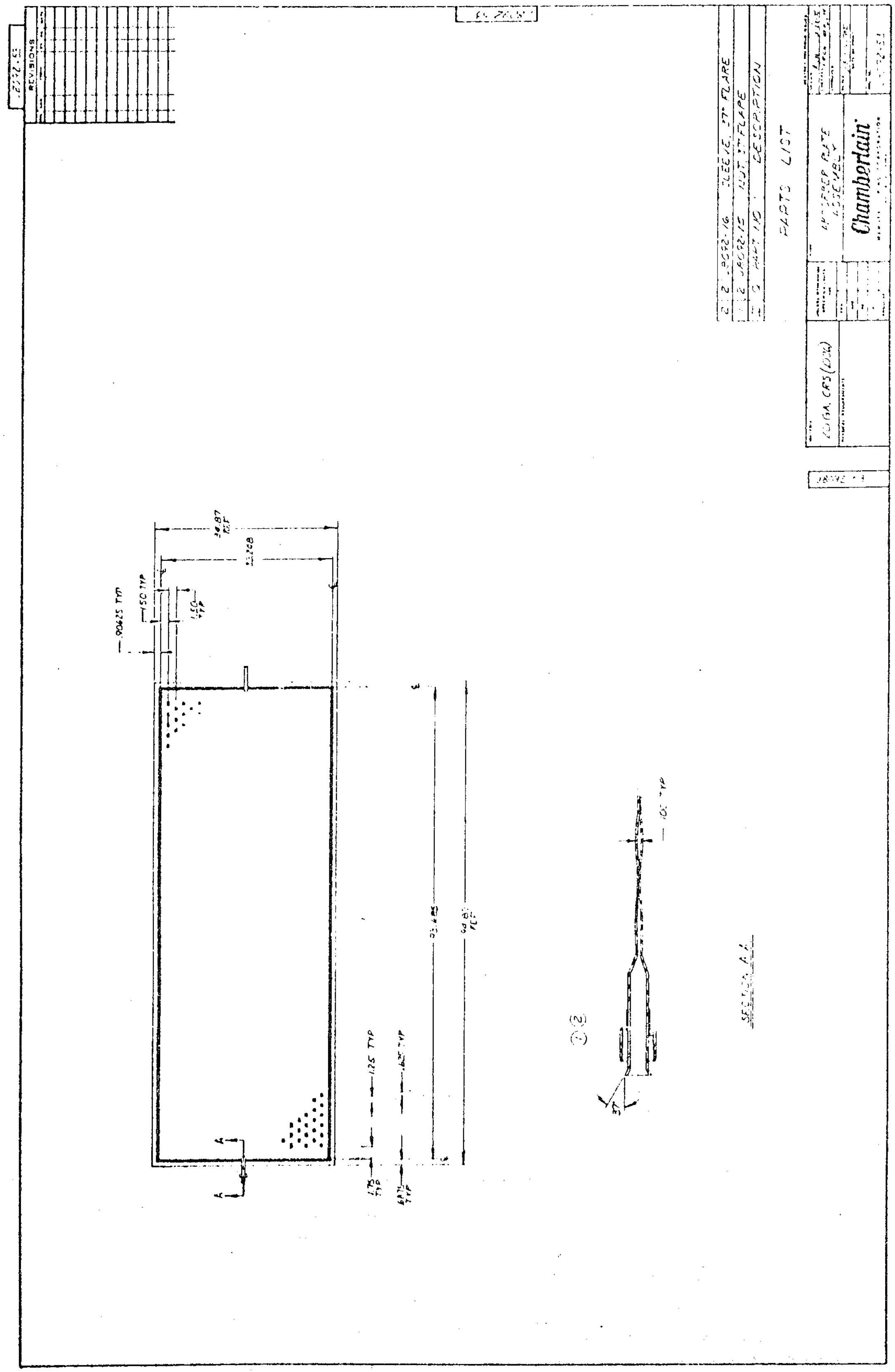
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SECTION A-A

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

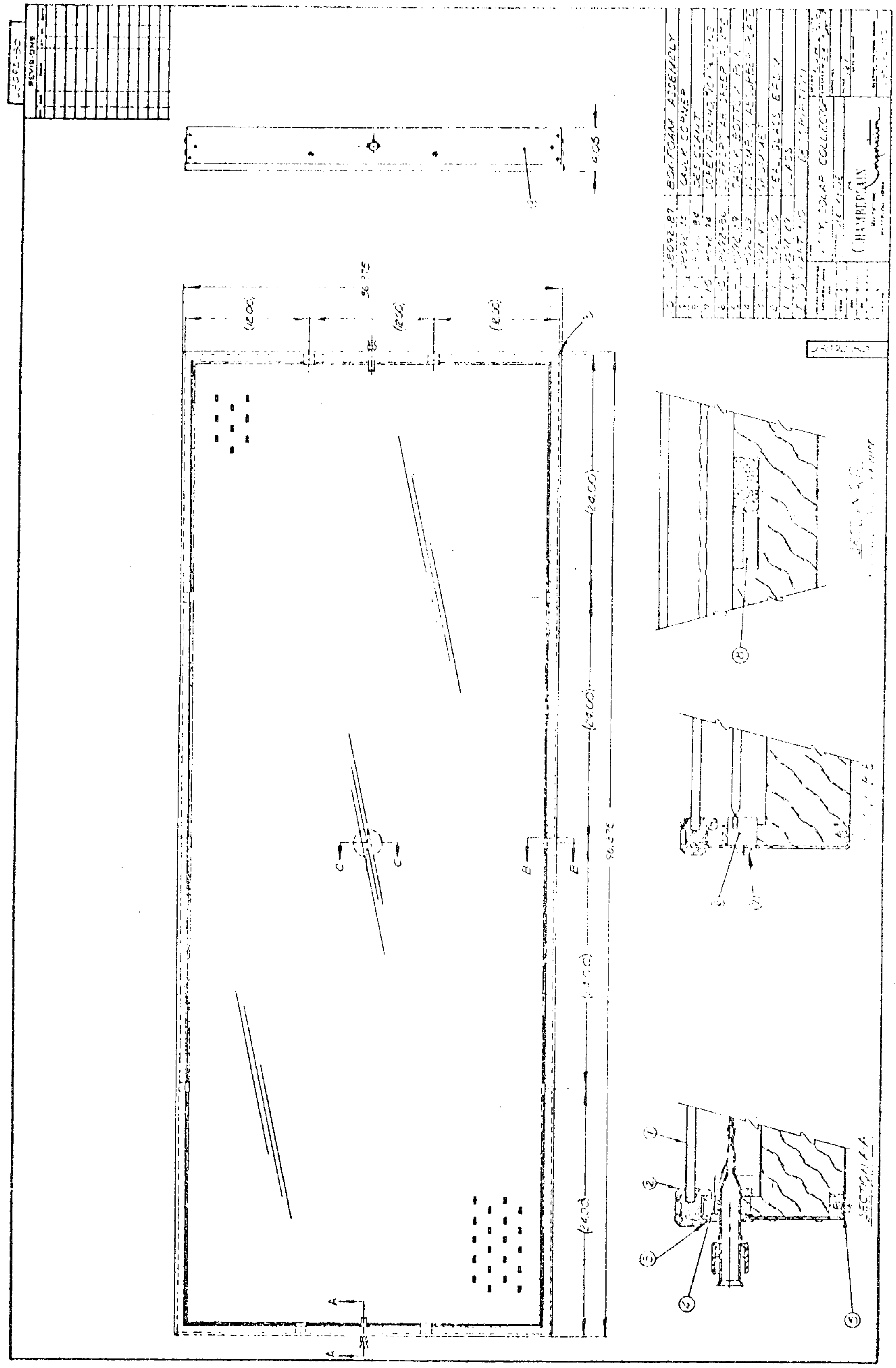
SCREW, SLOTTED PAN HD. TYPE AB

#10 - 16 X.3/8 LONG
STAINLESS

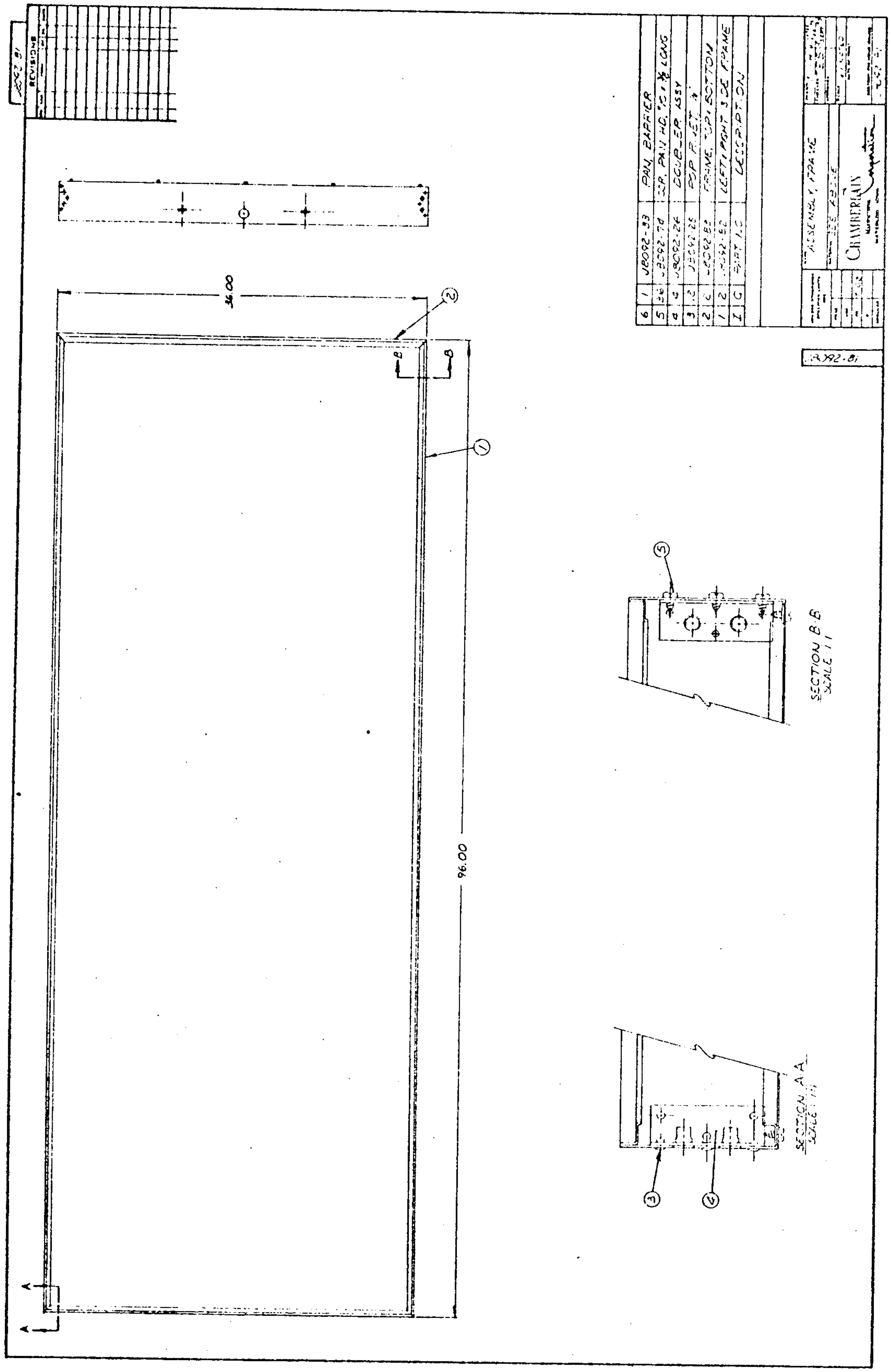
UNLESS OTHERWISE SPECIFIED LIMITS ARE	
FRAC.	
.000	
.00	
.0	
ANGULAR	

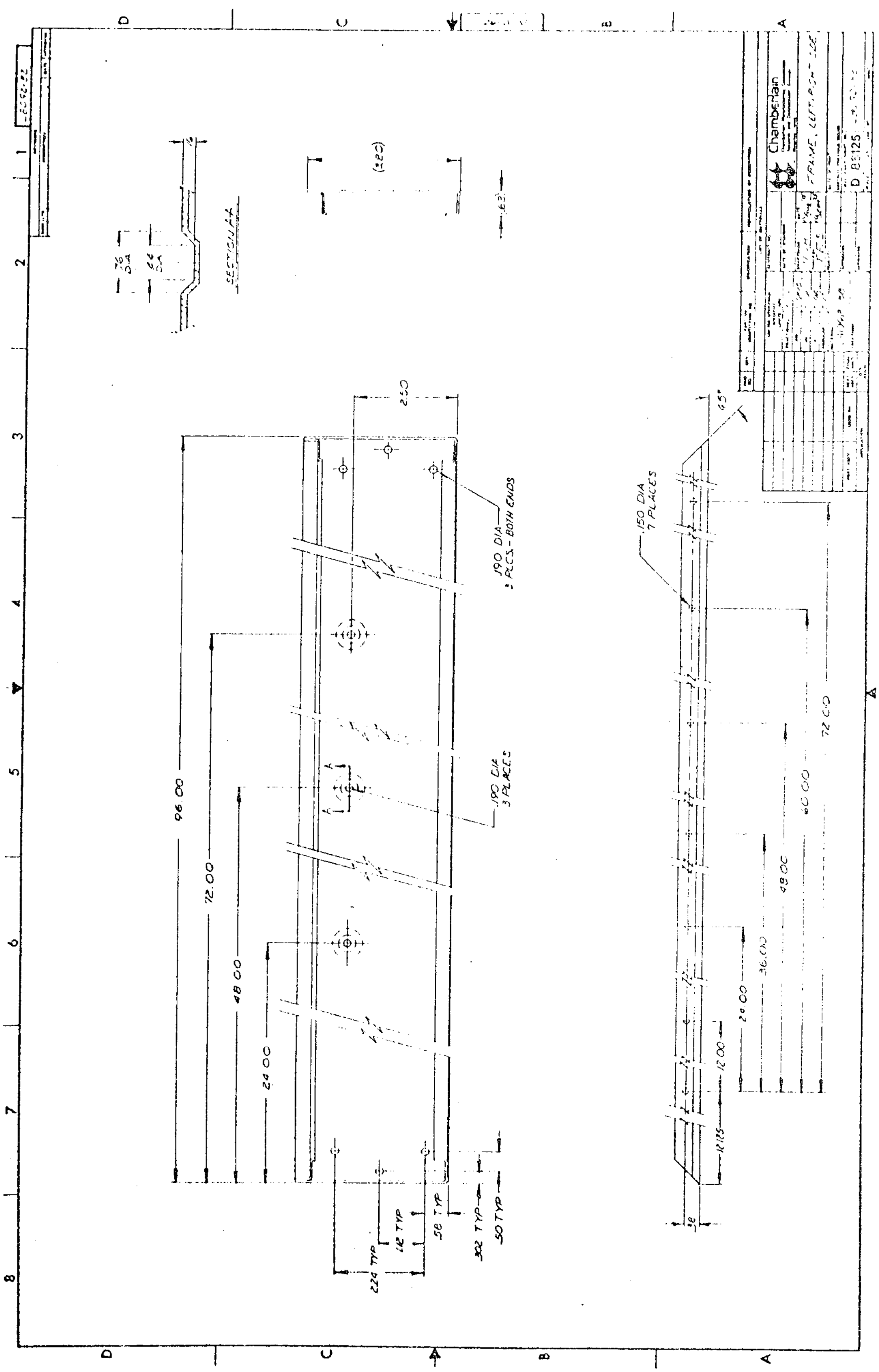
NAME	
SCREW PAN HEAD	
MATERIAL	
CHAMBERLAIN Corporation MANUFACTURING WATERLOO, IOWA	

		DATES
DRAWN		
CHECKED	RCH	13 July 75
APPROVED		
SCALE		
DATE OF PRINT		
DESTROY PREVIOUS ISSUES		
J8092-74		

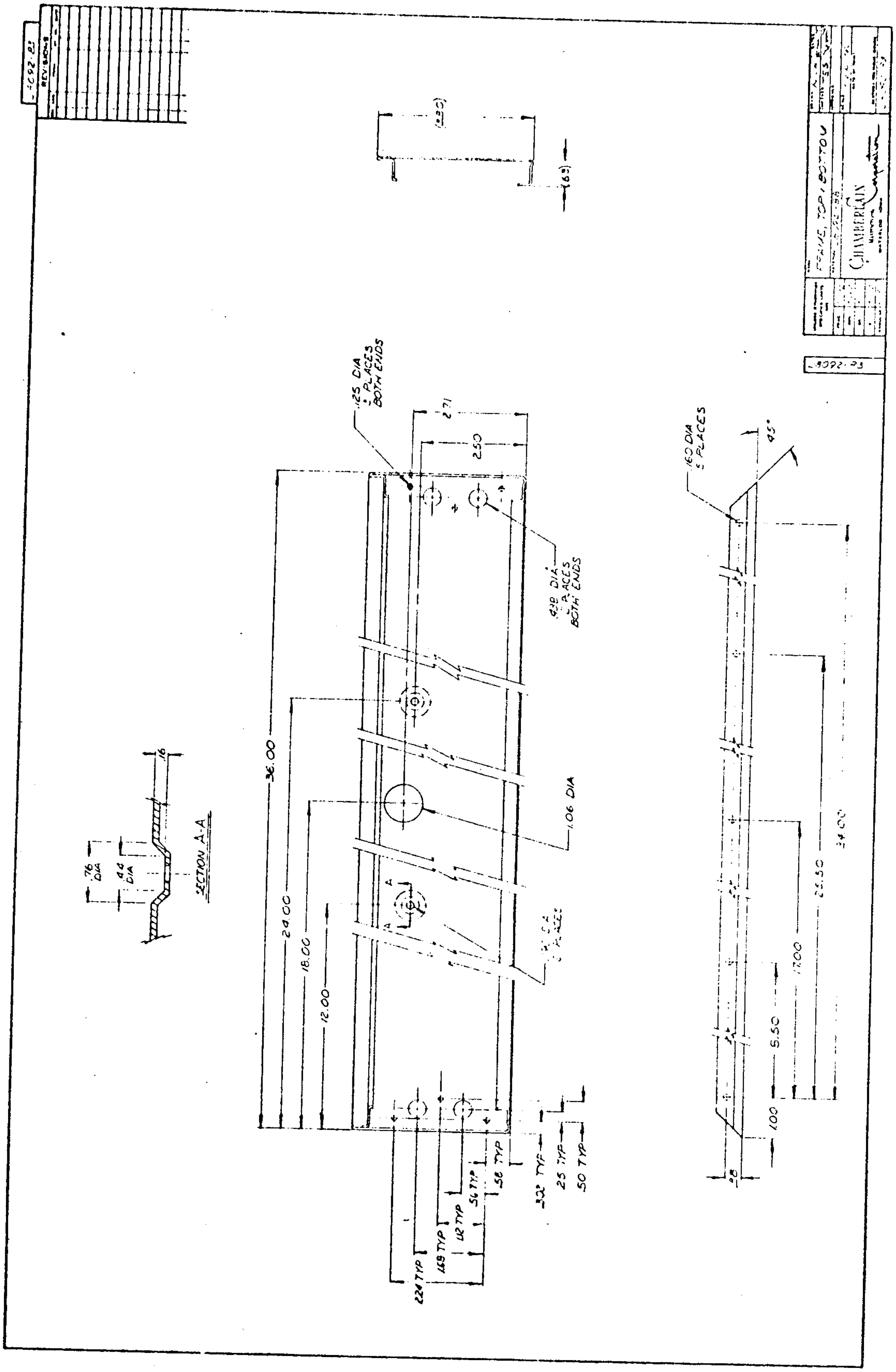


REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR





SECTION A-A
.76 DIA
.62 DIA
2.50
.190 DIA 3 PCCS - BOTH ENDS
.190 DIA 3 PLACES
96.00
72.00
48.00
24.00
.150 DIA 7 PLACES
45°
72.00
60.00
49.00
36.00
24.00
12.00
12.125
.224 TYP
.112 TYP
.58 TYP
.312 TYP
.50 TYP
Chamberlain
D 83125


SECTION A-A
.76 DIA
.44 DIA
36.00
24.00
18.00
12.00
1.06 DIA
.125 DIA
BOTH ENDS
.160 DIA
5 PLACES
45°
34.00
23.50
17.00
5.50
1.00
2.50
.25 TYP
.50 TYP
.56 TYP
CHAMBERLAIN

DESICCANT: W. R. GRACE, DAVISON CHEMICAL DIVISION, AIR DRYER - SILICA GEL, PART NO. X1009

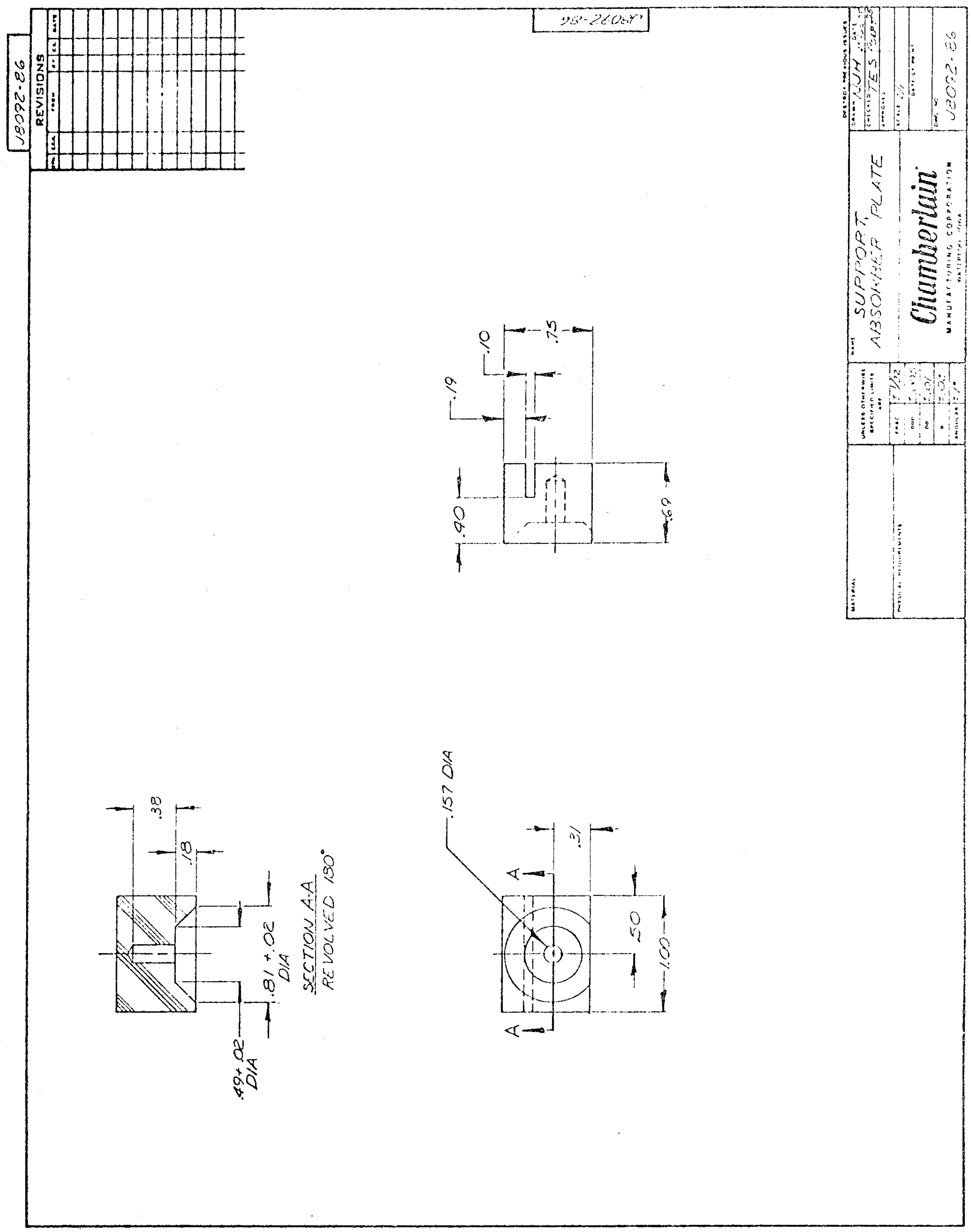
UNLESS OTHERWISE SPECIFIED LIMITS ARE		NAME DESICCANT	DRAWN	DATES
			CHECKED TES	5 SEPT 75
		MATERIAL	APPROVED	
FRAC.			SCALE	
.000		CHAMBERLAIN MANUFACTURING Corporation WATERLOO, IOWA	DATE OF PRINT	
.00				
.0			DESTROY PREVIOUS ISSUES	
ANGULAR			J8092-84	

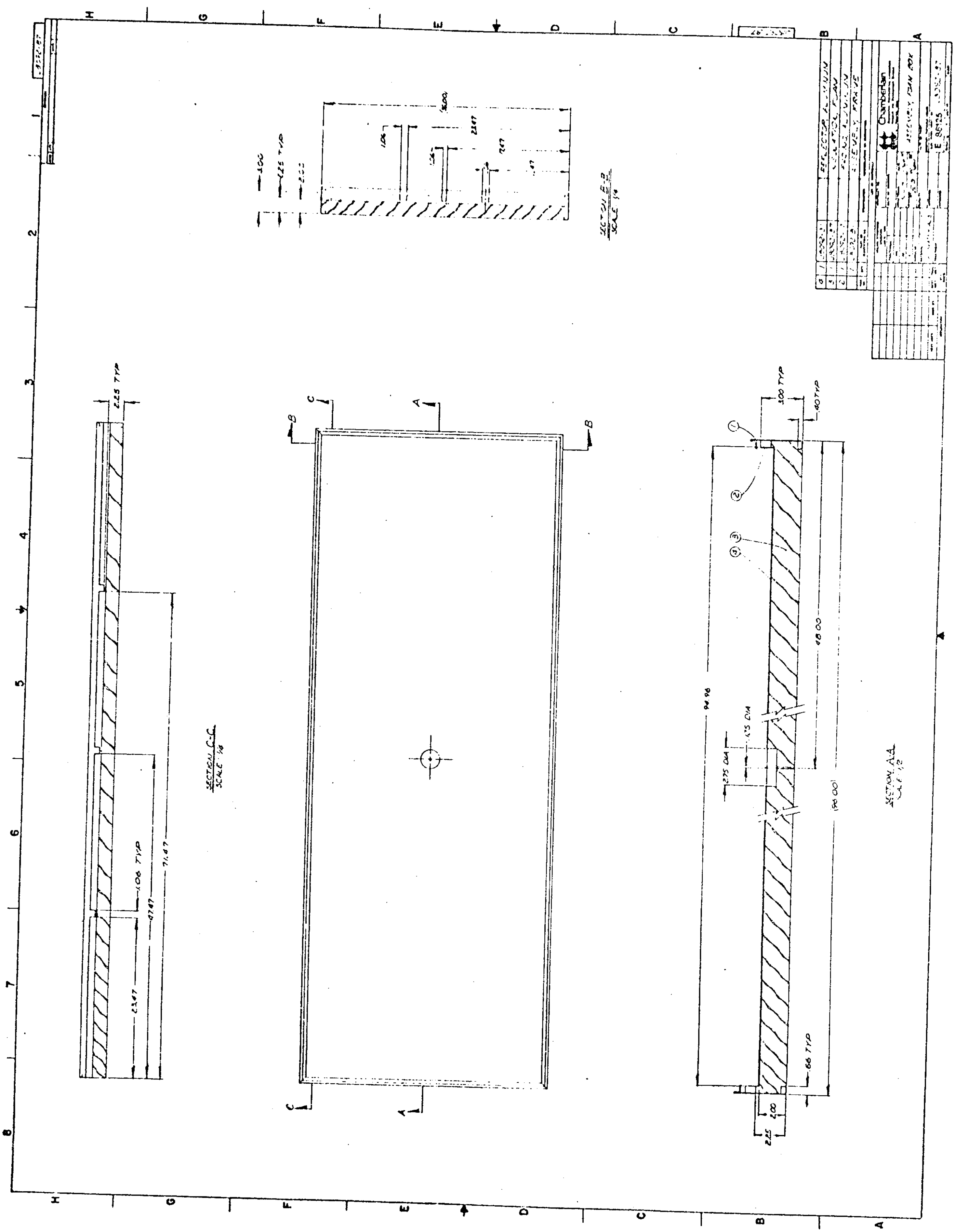
REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

RIVNUT, FLAT HEAD, KEYLESS, CLOSED END,
#10-32UNF-3B THREAD, O.D. .250-.004, LENGTH:
.781±.015 (UNDER HEAD); MATERIAL: C1108-C1110;
GRIP RANGE: .010-.080

B. F. GOODRICH RIVNUT NO. S10B80

UNLESS OTHERWISE SPECIFIED LIMITS ARE		NAME RIVNUT	DRAWN	DATES
			CHECKED TES	5 SEPT 75
FRAC.		MATERIAL	APPROVED	
.000		CHAMBERLAIN MANUFACTURING Corporation WATERLOO, IOWA	SCALE	
.00			DATE OF PRINT	
.0			DESTROY PREVIOUS ISSUES	
ANGULAR			J8092-85	


J8092-86
REVISIONS
SUPPORT,
ABSORBER PLATE
Chamberlain
MANUFACTURING CORPORATION
J8092-86
.10
.75
.19
.90
.69
.157 DIA
.31
.50
1.00
.38
.18
.81 +.02 DIA
.49+.02 DIA
SECTION A-A
REVOLVED 180°
A
A



SECTION C-C
SCALE 1/4
SECTION A-A
SECTION B-B
2.25 TYP
1.06 TYP
47.47
71.47
23.47
94.96
48.00
96.00
2.75 DIA
1.75 DIA
1.00 TYP
.80 TYP
.66 TYP
4.00
2.25

BLACK CHROME PLATING

BASE MATERIAL: NICKEL PLATE; DULL; 1.0-2.0 MILS THICK

BLACK CHROME: THICKNESS AND SURFACE CONDITION AS REQUIRED TO PROVIDE THE FOLLOWING OPTICAL PROPERTIES:

ABSORPTANCE	.95
EMITTANCE	.17

NOTE: PRODUCTION SPECIFICATION TO BE ESTABLISHED AT THE TIME OF INITIAL PRODUCTION

UNLESS OTHERWISE SPECIFIED LIMITS ARE		NAME: PLATING, BLACK CHROME	DRAWN	DATES
			CHECKED	
		MATERIAL	APPROVED	
FRAC.			SCALE	
.000		CHAMBERLAIN MANUFACTURING Corporation WATERLOO, IOWA	DATE OF PRINT	
.00				
.0			DESTROY PREVIOUS ISSUES	
ANGULAR			J8092-89	

COPPER OXIDE COATING

BASE MATERIAL: COPPER PLATE; MINIMUM OF 0.3 MIL THICK

COPPER OXIDE - THICKNESS AND SURFACE CONDITION AS REQUIRED TO PROVIDE THE FOLLOWING OPTICAL CONDITIONS:

ABSORPTANCE	.90
EMITTANCE	.12

NOTE: PRODUCTION SPECIFICATIONS TO BE ESTABLISHED AT THE TIME OF INITIAL PRODUCTION.

UNLESS OTHERWISE SPECIFIED LIMITS ARE		NAME: COATING, COPPER OXIDE	DRAWN	DATES
FRAC.		MATERIAL	CHECKED	
.000		CHAMBERLAIN MANUFACTURING Corporation WATERLOO, IOWA	APPROVED	
.00			SCALE	
.0			DATE OF PRINT	
ANGULAR			DESTROY PREVIOUS ISSUES	
			J8092-90	

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